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A METHOD FOR ROENTGEN EXAMINATION OF THE POSTERIOR URETHRA, PROSTATIC DUCTS AND UTRICLE (UTRICULOGRAPHY)

by

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The prostatic utricle in the male was first described by MORGAGNI, who called it the *sinus pocularis*. It consists of the remnants of the fused lower ends of Müller's ducts, corresponding to the vagina and cervix uteri (TOURNEUX 1888, PALLIN 1901, KEITH 1948 and BRANDT 1949). Accordingly the utricle is unpaired and is situated medially in the colliculus seminalis. It is normally pear-shaped, about 10 to 12 mm long, and at the most 3 to 4 mm wide (DELBET 1923).

HOWARD (1948) claimed that enlargement of the prostatic utricle is a sign of defective virilism (intersexuality). Of 14 hypospadiacs examined by endoscopy with injection of contrast medium directly into the utricle he found this organ definitely to be enlarged in 10.

Urethrocystography by conventional methods will seldom show the prostatic utricle. Thus, EDLING (1949) reported a filling in only 17 of 700 routine urethrocystographies. In none of his 29 normal controls was any such filling obtained.

MORALES and ROMANUS (1952) obtained a filling of the prostatic ducts in 42 out of 89 cases, the ducts being demonstrated better with a viscous contrast medium than with an ordinary water-soluble medium. In 4 cases

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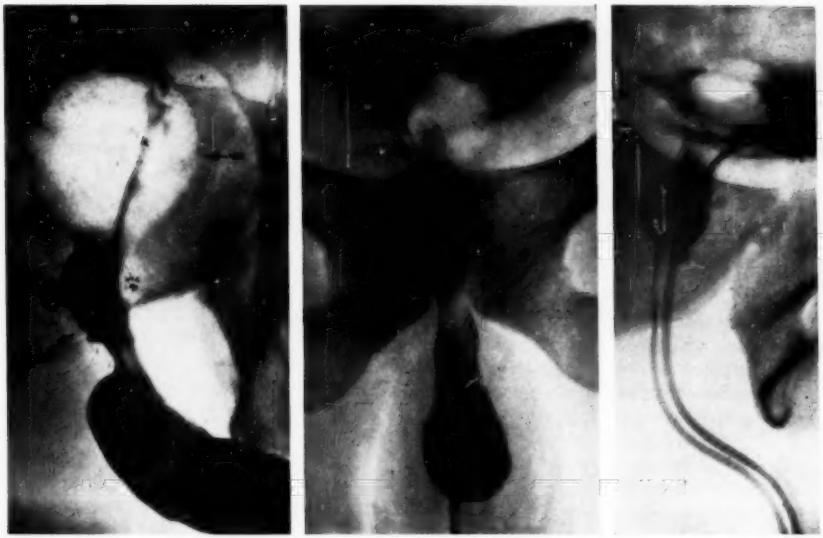


a b c

Fig. 1. Normal findings. a) Man, aged 56, with symptoms of cystitis. At → inflated balloon in the bladder. At ↠ colliculus seminalis. Filling of prostatic ducts. b) and c) Man, aged 24. Epididymitis 2 years previously. Prostatic urethra can be dilated below the internal sphincter. Some filling of prostatic ducts.

the seminal vesicles were also unexpectedly shown. They described cases with a filling of the prostatic utricle, but did not say in how many the pouch had been demonstrated. ROMANUS (1953) examined 35 of 117 patients with pelvo-spondylitis urethroscopically. In 2 he discovered an enlarged prostatic utricle, of which a filling was afterwards obtained on injection of the contrast medium directly into the utricle via a catheter passed through the urethroscope (ROMANUS 1951).

The method described below was originally devised for the roentgen examination of the seminal vesicles. It was assumed that occlusion of the pars prostatica urethrae by means of a balloon catheter and injection of the contrast medium via one of the catheter channels opening opposite the colliculus seminalis would permit injection of the contrast medium into the occluded part under much higher pressure than that achievable by ordinary urethrocystography. But no filling was obtained of the ejaculatory ducts or seminal vesicles. On the other hand, the method appeared to be useful in the examination, for example, of the prostate, and especially for demonstrating the size of the prostatic utricle.

Method. Before the examination the prostatic gland and the seminal vesicles should be drained by massage. The posterior urethra is shut off by means of a three-channel catheter with an inflatable balloon (20 ml air); on slight withdrawal of the catheter the balloon occludes the internal orifice of the urethra. The anterior urethra is then occluded by tying a length of ordinary thin rubber tubing round the root of the penis. In the beginning we used so-called tandem catheters with two balloons, the smaller (5 ml) of the two occluding the urethra in the most posterior part of the pars anterior; this, however, was found to make the method unnecessarily complicated. One of the channels in the catheter is used for draining the urinary bladder; when the floor of the bladder is drawn down, strong vesical contractions are prone to occur and drainage of the bladder should therefore be permitted. The third channel is used for the injection of the contrast medium and its opening should be about 1 cm below the balloon, *i. e.* at the level of the colliculus seminalis when the catheter is in position. During injection the catheter is drawn down rhythmically in order to produce some variation in the occluding pressure against the floor of the bladder. This prevents any compression of the colliculus seminalis by too constant a traction (Fig. 1).

Utriculography

Twenty-two patients were examined by the method. Five of them had pelvospondylitis (Romanus and Ydén 1955) and 17 had haematospermia or urethral symptoms. In 6 cases a filling was obtained of the prostatic utricle. In 2 (Cases 1 and 2 below) it was pathologically enlarged and in 1 the enlargement was less marked (pear-shaped and 14 by 6 mm in diameter). The prostatic ducts were demonstrated in 13 of the 22 cases (Figs. 1 and 2), and in 6 of them the filling was so marked that it might possibly be classified as parenchymatous.

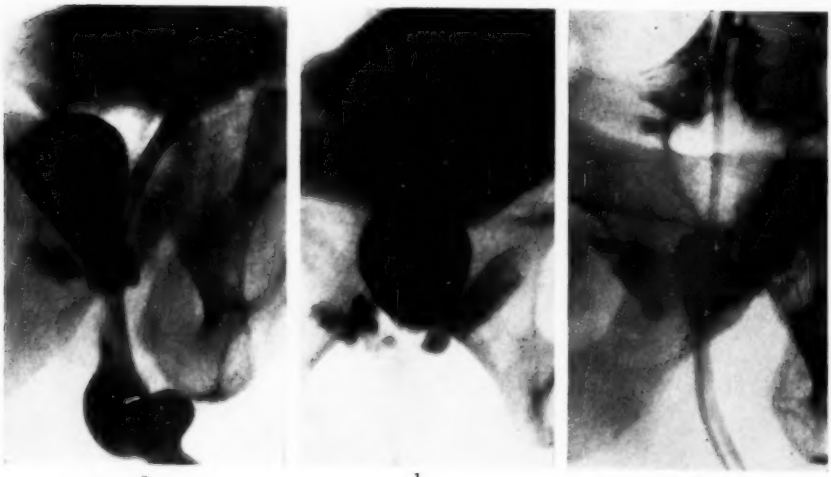
In 9 cases no filling was obtained of the prostatic ducts, but in almost all of these the examination was incomplete because of the discomfort caused, among other things by intense bladder contractions. In patients without demonstrable pathologic changes a local distension of the prostatic urethra was observed below the internal sphincter. This observation might be useful in the evaluation of the consistency of the prostatic gland surrounding this part of the urethra (Fig. 1 b and c).

In no instance was any filling obtained of the ejaculatory ducts or seminal vesicles. The method was also tried in 3 cadavers: in none did the contrast medium enter the ejaculatory ducts, but in all the prostatic ducts were filled.

In the 5 patients with pelvospondylitis the method failed to demonstrate any pathologic signs in the posterior urethra.

a b

Fig. 2. Case 1. Urethrography with Umbradil-Viscous U. a) Retrograde, b) micturition urethrography on the same occasion. No filling of prostatic utricle by this method. Some filling of prostatic ducts.



a b c

Fig. 3. Same case. a) Demonstration of large utricle by examination with balloon catheter; also more extensive filling of prostatic ducts. b) Filling of utricle persisted after withdrawal of catheter. c) Appearences after 18 months' therapy. Prostatic urethra could now be dilated normally below the internal sphincter (as in the normal case of Fig. 1 b and c). No filling of utricle.

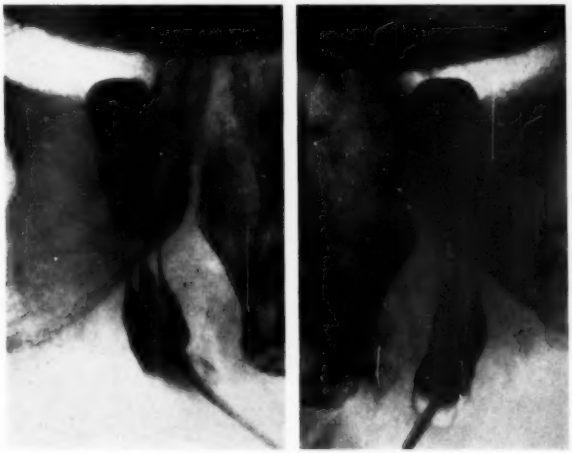


Fig. 4. Case 2. Extreme hypospadia with the urethra opening at the base of a small penis. Presumably intersexuality. Small testes. Enlarged and elongated utriculus. No filling of prostatic ducts. Prostatic gland very small on palpation.

Case 1. A man, aged 49. For the previous 6 months he had noticed blood and sometimes clots at the end of micturition. He had no pain. On clinical examination on 14 July 1953, the prostatic gland was found to be of ordinary size and consistency. Palpation produced a purulent urethral discharge, for which the patient was examined 4 days later by urethrocystography and also by utriculography (Figs. 2 and 3). Fluoroscopy showed how an enlarged utricle was successively filled with contrast medium with every downward pull of the catheter. In the roentgenograms the enlarged utricle measured 33 by 24 mm in diameter. The prostatic ducts were also demonstrated. After the examination the upper part of the enlarged utricle could be palpated between the upper margin of the prostatic gland and the urinary bladder. Digital massage completely drained the utricle of its content (fluoroscopic control) which was passed via the urethra as purulent secretion. The patient was treated for 18 months with prostatic massage. Small blood clots were occasionally passed in the urine. The patient felt well and showed no other signs of a pathologic condition.

At follow-up on 18 February 1955 no filling of the utricle was obtained (Fig. 3 c). In January 1957 palpation and the urinary sediment were normal both before and after prostatic massage.

Case 2. A man, aged 66, with severe hypospadias. The urethra emptied at the root of a small penis. A distinct furrow divided the scrotum, which contained small testes, into two halves. He was admitted to hospital on 11 March, 1955 because of acute retention after an alcoholic bout. During the previous half year he had increasing frequency and urgency of micturition, especially at night. Palpation revealed a small, hard prostatic gland.

On 16 March, 1955, utriculography was performed with a balloon catheter. Ordinary urethrocystography was not possible owing to the hypospadias. A filling was obtained of a pear-shaped prostatic utricle, which in the roentgenogram measured 37 by 15 mm in diameter (Fig. 4). The prostatic ducts were not demonstrated. In this case the filling also persisted after withdrawal of the catheter.

SUMMARY

A method is described for the roentgen examination of the posterior urethra and the prostatic utricle by the injection of contrast medium under high pressure into the occluded posterior part of the urethra.

ZUSAMMENFASSUNG

Eine röntgenologische Untersuchungsmethode der Urethra posterior und des Utriculus prostaticus wird beschrieben. Hierbei wird die Injektion des Kontrastmittels unter hohem Druck in den okkludierten hinteren Teil der Urethra vorgenommen.

RÉSUMÉ

Description d'une méthode d'examen radiographique de l'urètre postérieur et de l'utricule prostatique par injection de moyen de contraste sous forte pression dans la partie postérieure obstruée de l'urètre.

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FROM THE CENTRAL HOSPITAL OF CENTRAL FINLAND (DIRECTOR: OSKAR HERPOLA), JYVÄSKYLÄ, FINLAND

TOMOARTHROGRAPHY OF MENISCAL LESIONS OF THE KNEE-JOINT

Fifteen verified cases

by

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Positive or negative contrast media, as well as a combination of the two, may be employed in the examination of the menisci of the knee-joint.

In comparisons of arthrographic and operative findings the percentage of errors varies widely in different reports. SEVASTIKOGLOU (1954), who used a positive contrast medium, had 42.4 per cent of errors, whilst LINDBLOM (1948) had only 5 per cent. In the series of cases reported by BÖHLER (1943) 15 to 20 per cent had been erroneously diagnosed by pneumoarthrography, whilst SACHS et coll. (1950) reported 13.5 and ARCHIMBAUD (1953) only 2.9 per cent of errors. OGGIONI (1949) had poor results by both these methods, the percentage of errors being 87.5.

The technique and interpretation of the films is difficult and it seems that the percentage of correct diagnoses is high among authors with an extensive material and hence obviously a great deal of experience. This experience can only be acquired in large special hospitals, particularly as clinicians probably request arthrographies only from roentgenologists who have mastered the technique.

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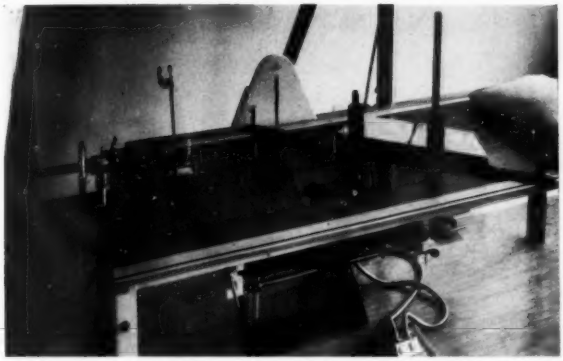

Fig. 1. Apparatus for securing pelvis and exerting traction on extremity, ready for examination of left knee.

One of us (P. K.) in 1954 introduced a combination of a tomographic technique with arthrography, believing that this might provide better information than that previously obtainable. FAGERBERG recently published an extensive paper on tomography of the knee-joint, in which a positive contrast medium had also been used as an aid. HAUCH (1952) experimented with tomography in connection with pneumoarthrography, and BAYER and JELINEK (1953) with tomograms obtained parallel to the tibial condyles and a positive contrast medium. FAGERBERG's conclusions regarding the value of the method in routine studies were negative. As our method differs from those used by others, and in view of the fact that we consider its prospects to be good, there seems to be some justification for a brief report.

Technique. An ordinary Siemens Horizontal Planigraph with rectilinear movements is used. It is equipped with a clamp, fork-shaped at both ends, by means of which the pelvis of the patient is secured to the table. This clamp, which can be positioned by manually operated screws in grooves on either side of the table, is drilled with holes 5 cm apart into which pegs padded with latex foam rubber can be inserted (Fig. 1). For the frontal view, the extremity to be examined lies along the median line of the table with one peg between the thighs and a second peg in such a relation to the pelvis (Fig. 2 a) that when the patient is turned on his side for the lateral view, this peg remains below the anterior superior iliac spine, whilst the first peg supports the pelvis close to the tuber ischii (Fig. 2 b). To stretch the extremity longitudinally the shaft and shoe of a plaster table are fixed with a manually operated screw to an upright metal rod mounted at the end of the examination table;

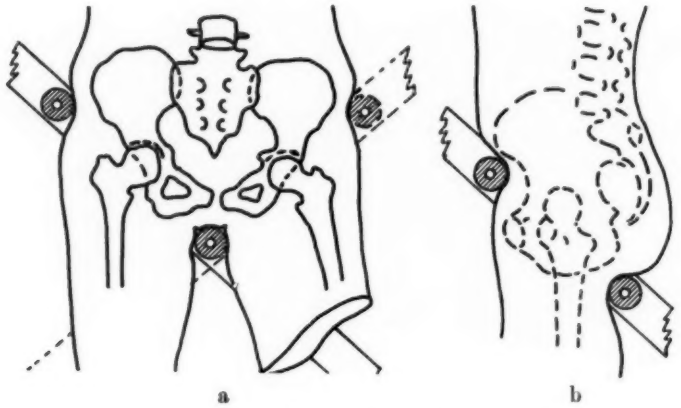

Fig. 2. Schematic sketches showing: a) Securing of pelvis to table for frontal tomoarthrography of right knee. b) Securing of pelvis to table for lateral tomoarthrography of right knee.

the height of the shaft can thus be regulated. A few small pieces of foam rubber are placed under the patient's pelvis (Fig. 1). The first attempts showed that the use of a positive contrast medium was superior to pneumoarthrography and the double-contrast method. So as to ensure an adequate accumulation of the opaque medium on the surfaces of the meniscus, the joint under examination is placed under slight traction in a longitudinal direction, and simultaneously the joint space is opened by stretching the knee either medially or laterally, depending on whether the medial or lateral meniscus is to be examined.

In order to prevent the proximal part of the joint cavity from filling with contrast medium, a small piece of foam rubber is placed transversely and proximal to the patella and tied with an elastic bandage; the latter is wound from the back of the knee-joint obliquely to the distal part of the joint, around the upper portion of the leg, again behind the knee-joint so as to cross the previous turn, and back to the proximal part of the joint. The patellar region is in this way left exposed. The puncture of the joint cavity is performed according to LINDBLOM's technique. Slight traction is applied to the extremity, and the joint cavity is filled with a 50 per cent water-soluble contrast medium, preferably Joduron (Cilag); in spite of the high concentration, it has not proved necessary to anaesthetize the joint cavity when this contrast medium is used. The volume injected is about 15 ml, of which some 10 ml are then withdrawn. The puncture wound is sealed aseptically, the traction is released, and for one minute, if the lesion permits, extreme flexion and rotation movements of the knee-joint are performed.

Fig. 3. Positioning of patient for lateral tomoarthrography of medial meniscus; cushion under leg.

With the patient supine, the extremity is again placed under as much traction as can be borne without pain. An elastic tape is fastened somewhat distally to the knee-joint and the extremity is drawn sideways in the direction of the meniscus to be examined, the knee-joint being supported by padded cushions placed under the calf and thigh. A scale rule of lead, calibrated in centimetres, is placed vertically near the joint space and an ordinary lateral view 'scale diagram' of the joint obtained.

Tomograms at 0.5 cm distances between layers are now taken, first from the side clinically suspected and then from the opposite side after the direction of the side-traction has been changed. Exposure factors: 60 kV, 160 mAs, F. F. D. 140 cm, Potter Bucky diaphragm, Sinegran-Saphir screens.

The traction in the longitudinal direction is released but not removed and the patient is placed on the side of the extremity under investigation. The other extremity is flexed against the trunk and supported with cushions. Traction is again applied to the extremity. When the medial meniscus is under investigation the medial part of the joint may be opened out by elevating the cushions supporting the extremity (Fig. 3); when the lateral meniscus is to be examined, sand-bags are placed on the extremity at a sufficient distance from the joint. The scale diagram and tomograms are made as described above. Oblique projections may if necessary also be obtained. After the examination the extremity is placed upon a splint for one or two days.

Evaluation of the roentgenologic findings. In the evaluation of the tomograms it is advisable to reconstruct their relative positions in relation to the knee-joint with the aid of the scale diagram.

The normal variations and pathologic findings are described in detail in FAGERBERG's paper.

Material. The material includes 15 cases examined tomoarthrographically and clinically, and operated upon. Both the clinical investigations and the operations in all these cases were performed by one of the writers (M. K.).

In 7 cases the clinical signs were so unmistakable that operation would have been indicated even without a roentgenologic examination. In 8 cases the clinical signs were regarded as uncertain.

The commonest tomoarthrographic abnormality was the division of the meniscus wedge observed in 10 cases.

The meniscus was separated from the capsule in 1 case.

The meniscus wedge appeared blunt in 1 case.

The normal site of the meniscus was filled with opaque medium in 1 case.

The meniscus wedge was markedly deformed in 2 cases.

A fissure on the surface of the meniscus wedge, filled with opaque medium, was noted in 1 case.

The findings were negative in 1 case.

The relationship between the roentgenologic and clinical signs can be seen from the following table:

	Clinical signs	Roentgenologic signs	
		Positive	Negative
Definite	7	6	1
Uncertain	8	8	—

The roentgenologic findings were confirmed at operation.

The operations were performed by the most conservative technique possible. The joint was never opened widely enough to necessitate severing the extensor mechanism or the collateral ligaments; these were always left intact. Operation was invariably performed in the quadrant where a rupture was anticipated from the roentgenologic examination. The procedures employed were largely those described by BANKS & LAUFMAN (1953).

A rupture or fissure of the meniscus was established at operation in 14 cases. In 2 of these, both menisci were ruptured. One patient showed clinical signs clearly indicative of a lesion of the meniscus, but on tomoarthrography and operation the latter was found to be intact.

Fig. 4.

Fig. 5.

Fig. 4. Normal finding in lateral tomogram. The section passes through middle part of meniscus which is visible along its whole length between the layers of contrast medium (anterior and posterior wedges united).

Fig. 5. Lateral meniscus, lateral view. Relatively broad fissure in inferior surface of anterior wedge.

The patho-anatomic changes in all the cases were located in the quadrant indicated by the tomoarthrography. In 12 cases the interpretation of the tomograms was completely correct, but in 2 cases abnormal changes were found without these being defined.

The findings at tomoarthrography and operation were thus in good agreement.

Discussion

In his detailed theoretical discussion, FAGERBERG emphasizes that the greater the amplitude utilized the wider the parts of the curved surfaces that 'lie within the amplitude' and the more the marginal parts of the meniscus wedges are shown tomographically.

An amplitude of 45° has been used in the present material, and in Figs. 4 and 10 it will be noted that the peripheral parts of the menisci are demonstrated. When this greater amplitude is employed some types of blur (parallactic and lost-motion blur) are greater than FAGERBERG experienced with an amplitude of 20°. However, the changes such as ruptures and fissures which are shown are usually gross (Figs. 5, 6, 7, 8 and 10) and easy to define clearly, particularly if the surfaces of the menisci are well covered with contrast medium of high (50 %) concentration. It is of fundamental importance to employ sufficient traction both in a longitudinal direction and especially towards the meniscus to be examined. The advantage of this is clearly demonstrated in Fig. 9. The practice of filling the joint with a large quantity of contrast medium, of withdrawing the surplus amount to reduce residual shadows, and of effecting the tomography immediately after this, probably also helps in the result.

Fig. 6. Medial meniscus, lateral view. Posterior wedge divided.

Fig. 7.

Fig. 8.

Fig. 7. Medial meniscus, lateral view. Posterior wedge divided.
Fig. 8. Medial meniscus, lateral view. Anterior wedge divided, posterior wedge blunt and also ruptured.

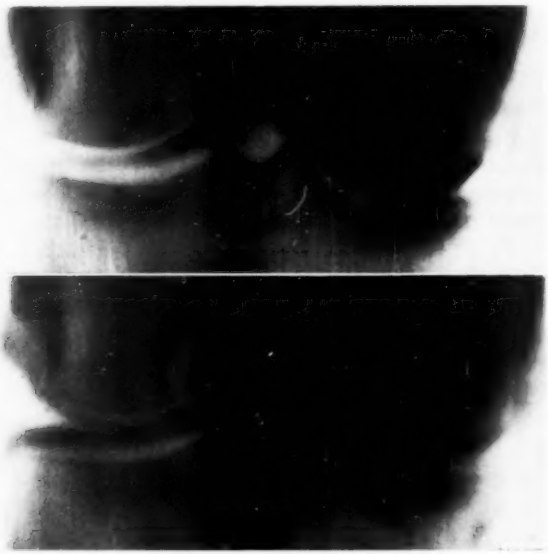

Fig. 9. The same sections in frontal tomography, but using traction towards the medial meniscus (*top*) and towards the lateral meniscus (*bottom*). The menisci are now clearly demonstrated.

Fig. 10. Frontal view. Rupture of the lateral meniscus in the posterolateral part. The tomographic section passes through posterior part of the normal medial meniscus.

The employment of a multidirectional tomograph would reduce residual shadows and help to counteract the disadvantage of the rectilinear tomograph pointed out by FAGERBERG, viz. that the tomographic effect is poor in the lateral parts of the joint in frontal tomography and in the anterior and posterior parts of the joint in lateral tomography. A possibly increased lost motion blur would hardly hamper its use. Unfortunately, no such tomograph was available.

The number of positive findings obtained probably resulted from the technique used. It should be noted that with FAGERBERG's technique, too, the results were nearly as good as with conventional arthrography. However, the most essential advantage of tomoarthrography is the ease of film interpretation. When anatomic conditions and the mutual relationship of tomograms in the third dimension are borne in mind, their interpretation does not require nearly so much experience as do the films obtained in conventional arthrography. The technique of simultaneous tomography will probably make the procedure as easy and the radiation dose as small as in the latter method.

The clinical signs of meniscal rupture are sometimes doubtful. Arthrotomy should not be utilized as a diagnostic aid until all other available methods have been tried. The tomoarthrographic technique described is, in our opinion, a very suitable method of indicating the quadrant involved, a factor of importance in planning an operation. The early promise shown by the method appears to warrant its serviceability being tried out in a larger material.

SUMMARY

A method of examining the menisci of the knee-joint by means of tomoarthrography is described. A material of 15 operatively verified cases is reported, including 8 clinically uncertain cases, in all of which good agreement between the tomoarthrographic results and the operative findings was obtained.

ZUSAMMENFASSUNG

Eine Untersuchungsmethode für die Menisken des Kniegelenkes mit Hilfe der Tomo-Arthrographie wird beschrieben. Ein Material von 15 operativ sichergestellten Fällen, welches 8 klinisch unsichere Fälle enthält, wird vorgelegt. In sämtlichen Fälle wurde gute Übereinstimmung zwischen den tomo-arthrographischen Ergebnissen und den operativen Befunden erzielt.

RÉSUMÉ

Description d'une méthode d'examen tomo-arthrographique des ménisques du genou. Les auteurs présentent une série de 15 cas vérifiés opératoirement, parmi lesquels 8 cas cliniquement douteux; dans tous ces cas les constatations opératoires ont confirmé les résultats de la tomo-arthrographie.

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FACTORS CONTRIBUTING TO THE FORMATION OF GAS IN THE FETUS IN CASES OF INTRA-UTERINE DEATH

by

Olov Fr. Holm

The occurrence of free gas in the fetus in cases of intra-uterine death has been discussed by the present author in recent publications (HOLM 1954, 1956 and 1957). These were based on systematic investigations of all women in whom intra-uterine fetal death occurred, treated in the Obstetric Department of this hospital from October 1953; all the dead fetuses were examined.

The author's material now comprises 56 dead fetuses which were all examined after partus, and among which were 37 cases which had also been examined before partus. A further number of cases were examined for suspected intra-uterine death although it was later found that the fetus had been alive.

Previous to this the literature contained only a few reports on free gas observed in dead fetuses, and these only dealt with isolated or a small number of cases: ROBERTS (1944) 2 cases, DAVIDSON (1949) 2 cases, NASH (1950) 2 cases, TAGER (1952), and KETTUNEN (1952) 1 case each. According to an editorial note in the Year Book of Radiology 1955/56 these reports were met with some scepticism by radiologists and obstetricians alike. More recently, however, the number of published reports

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has increased, some of these dealing with a larger number of cases: CRICK and SIMS (1953) 7 cases, HOLM (1954) 1 case, MARGOLIS and JONES (1954) 2 cases, SAMUEL and GUNN (1955) 15 cases, HOLM (1956) 13 cases, ELLENBOGEN et coll. (1956) 1 case, and HOLM (1957) a further 7 cases.

Now, it appears reasonable to regard the following observations as confirmed.

1) The gas appears always to be present in the vascular system, particularly in the heart, aorta, and in some of the large arteries. There is frequently gas also in some of the large veins. In the abdomen, the regions of the liver and the spleen are particularly involved. In some instances, there is gas also outside the vascular system as, for example, in the peritoneal cavity or skull, or the gas may diffusely infiltrate the tissues of the retroperitoneal region. Such conditions have been reported in 1 of ROBERT's cases, in 2 of CRICK and SIMS', in both the cases reported by MARGOLIS and JONES, and they occurred in 8 cases of the author's own material.

2) Free gas in fetuses, in cases of intra-uterine death, is a fairly common finding. In the present material of 56 dead fetuses, gas was present in 32 cases.

3) The gas may be demonstrated roentgenographically with fair certainty before delivery. Thus, out of the 23 cases which were found to contain gas when examined after delivery, and which had also been examined before delivery, the prenatal presence of gas could be demonstrated in 18 cases.

4) The gas often appears early as compared with other roentgenologic signs of intra-uterine fetal death. In this material, a diagnosis could be obtained in 9 cases in this way within 3 days after fetal death was estimated to have occurred.

5) The gas is frequently the only roentgenologic sign of intra-uterine fetal death.

In the author's material, gas in the fetus has been found to be the most common sign of intra-uterine death. Other signs are as a rule more or less relative, and must be fairly advanced before they can be relied upon for establishing a diagnosis of death. A definite demonstration of gas in the fetus, on the other hand, constitutes an infallible sign of fetal death.

The phenomenon is therefore of practical importance from the roentgendiagnostic point of view. It is, however, of interest also from a more theoretical standpoint, viz. as regards the mechanism of the gas formation, about which nothing is known with certainty.

DAVIDSON believed that the gas formed during decomposition of certain blood elements. KETTUNEN, and SAMUEL and GUNN regarded Rh-immunization of the mother through the fetus to be a relevant factor

in the process of gas formation. It has previously been shown by the present author, however, that in this connection no significance can be attributed to the Rh-factor. SAMUEL and GUNN moreover assumed that the gas forms in the placenta, at a stage when the fetus is alive, and proceeds via the umbilical cord to the heart of the fetus where it causes gas embolism leading to death. Several factors are against these assumptions, however, as has been discussed in more detail elsewhere (HOLM 1957).

Bacteriologic tests on specimens taken from the blood of the fetuses have been carried out by CRICK and SIMS, and these authors have also analysed the gas; in most instances the bacteriologic tests showed no growth of micro-organisms. The gas in all their analyses was found to consist of almost pure nitrogen. These authors did not find it possible from their own investigations to explain the mechanism of gas formation, but the tests in their opinion strongly suggested that the gas formation was not due to bacterial activity. This is in agreement with views held by most authors as regards putrefaction, which is not believed to take place in a closed amniotic cavity.

It is improbable that any definite information as to the cause of the gas formation can be obtained from the analyses of the free gas, and this on account of the gas exchange which takes place when a given gas maintains contact with a fluid in which other gases are physically absorbed and which leads to a distribution depending upon the absorption coefficients and partial pressures of the respective gases.

According to MARGOLIS and JONES the most probable explanation would be that gas-forming bacteria are transferred from the blood of the mother via the placental barrier to the fetus, leading to septicemia and death and to agonal gas formation in the latter.

With the present work an attempt has been made to determine whether any particular property or pathologic process can be shown to bear some relation to factors responsible for the gas formation, and so make it possible to define the range of the problem. As far as it has been possible to ascertain, there is no record in the literature of a similar material having been subjected to a systematic treatment with this in view. The author's material has been divided into two groups: one comprising 24 cases in which no gas was revealed in the roentgen examination immediately after the delivery (the minus group), and the other comprising 32 cases which, in the examination immediately after partus, were found to contain gas (the plus group).

The following conditions in relation to the mother may possibly be regarded important in connection with the gas formation: 1) Age, 2) Number of earlier pregnancies, 3) Number of earlier abortions or dead fetuses, 4) Blood group according to the ABO-system, 5) Rh-factor, 6) Earlier diseases, and 7) Any illness affecting the mother during the actual pregnancy.

In the author's material, none of the factors (1) to (6) seem to have had any influence on the formation of the gas.

As regards factor (7) it was found that the most common diseases affecting the mother were *nephropathia gravidarum* and *albuminuria gravidarum*, which occurred in 16 cases and in none of these were associated with eclampsia or eclampsism: there were 5 cases in the minus group and 11 in the plus group. Diabetes mellitus was present in 4 cases: 1 in the minus group and 3 in the plus group. In 5 cases, vaginal bleeding occurred, and in two of these was definitely due to abruption of the placenta. These 5 cases were distributed with 2 in the minus group and 3 in the plus group. Pernicious anemia was present in 1 case, hypertonia in 1 case and polyarthritis in 1. Otherwise, no illness at the time had occurred among the mothers. A total of 30 mothers seem to have been quite well during pregnancy, according to the case reports; 14 of these belonged to the minus group and 16 to the plus group.

The material in question provides no criteria justifying the conclusion that any definite property or pathologic process associated with the mothers' condition could have been of importance in the development of gas in the fetus.

As regards the question of any special property or pathologic process concerning the fetus it is evident that the problem becomes much more complicated, because in this connection we have to deal with a number of unassessable factors. The sex of the fetus is of no importance; in the minus group there were 11 male and 13 female fetuses, and in the plus group the corresponding numbers were 15 and 17, respectively.

In 6 cases the fetuses died during parturition: 1 from injury caused by changes in the pelvic bones, 1 due to abnormal presentation, 1 from parturition injury of another kind, 2 due to abruption of the placenta, and 1 due to asphyxia. None of these was macerated and the fetuses did not contain gas. When death appeared before the delivery it was due in 5 cases to gravidotoxicosis, in 3 cases to utero-vaginal bleeding, without any further indication as to the cause. In 1 case erythroblastosis, and in 1 case an anomaly of the circulatory organs were the causes of death.

In 3 cases, the umbilical cord was knotted: in 2 cases, at least, so tightly that this was judged to have been the probable cause of death. These 3 fetuses all contained gas, which seems to support the author's view that the gas is formed in the fetus and not transported to it via the umbilical cord.

In the remainder of the cases it had not been possible to establish the cause of death.

The author has previously suggested that maceration influences the gas formation. Hemolysis occurs early in the process of maceration, and the blood fluid will then contain free hemoglobin. Gradually, hemo-

globin also escapes out of the blood vessels, and all the tissues may be imbibed with hemoglobin, which leads to a red-brown discoloration of the fetus (*fetus sanguinolentus*). Moreover, the hemoglobin also undergoes decomposition, and this will lead to the formation of bilirubin, among other substances.

The *degree of maceration* is generally divided into three stages. In Table 1, the present material has been assembled to show the degree of maceration according to the divisions adopted by MARTIUS et coll.

Table 1

Number of cases in different degrees of maceration with free gas

Degree of maceration	Examination performed	
	Before partus	After partus
0	No investigation	0 out of 6
I	0 out of 3	1 out of 6
II	6 out of 13	12 out of 17
III	12 out of 21	19 out of 27
Total	18 out of 37	32 out of 56

It will appear from a study of this table that even if the number of cases without, and with maceration in Stage I, are comparatively few, maceration is of essential importance in the gas formation. It is principally in Stages II and III that the gas is a common finding. A comparison of these two groups shows that the frequency of gas is about the same for both; this is in good agreement with the fact that the appearance of gas is a comparatively early sign of intra-uterine fetal death.

The material has also been divided into groups according to the *amount of gas* present: Group I containing small amounts of gas, Group II moderate amounts of gas, and Group III extremely large quantities of gas. These data have been collected in Table 2, which shows that in the majority of cases the amount of gas is considerably greater in Group III than in Group II, which confirms the assumption regarding the influence of maceration upon the development of gas.

Table 2

Number of cases with amounts of gas

Degree of maceration	Amount of free gas		
	1 Little	2 Moderate	3 High
0	0	0	0
I	1	0	0
II	5	6	1
III	3	5	11
Total	9	11	12

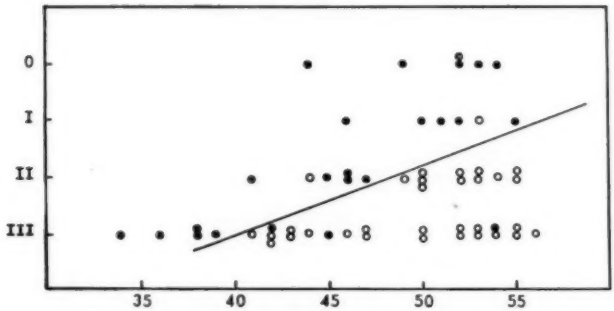

Diagram 1. Degree of maceration plotted against the fetal length in centimeters.
○ Cases with gas. ● Cases without gas.

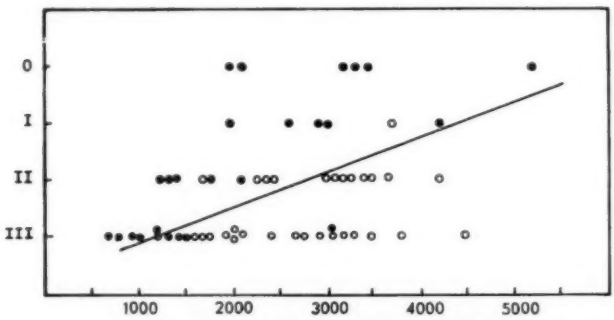

Diagram 2. Degree of maceration plotted against the weight of the fetus in grams.
○ Cases with gas. ● Cases without gas.

It may be observed in this connection that in all the cases in the author's material, in which gas was present also outside the vascular system, the fetuses were considerably macerated and all the tissues were extensively stained with blood pigment (*fetus sanguinolentus*).

For determining the age of the fetus with a view to obtaining an idea of the degree of maturation, it is customary to make use of data referring to the length and weight of the fetus. In the above two diagrams, all the cases in the author's material have been assembled to show: in Diagram 1 the degree of maceration plotted against the length, and in Diagram 2 the degree of maceration plotted against the weight of the fetus.

These two diagrams are univocal. The boundary line between the cases not containing gas and those in which gas was present is defined by a fairly straight diagonal. This seems to indicate that the degree of

maturation of the fetus is of essential importance for the development of the gas, and that a relationship exists between the degree of maceration and the degree of maturation. Gas is more frequent in the mature fetuses, even if the degree of maceration is not so marked, whereas the smaller fetuses in comparison require a higher degree of maceration for gas to be developed. No gas formation appeared in the very smallest fetuses, not even those that showed a very high degree of maceration.

Discussion

On the basis of the present investigation the following conclusions seem warranted:

1) The gas formation very probably takes place in the fetus proper.

2) The development of gas does not depend on any particular property or pathologic process associated with the mother.

3) The only positive factors which could be shown to be connected with the formation of the gas were the degrees of maceration and maturation of the fetus; the higher these become the greater their influence on the development of gas in the fetus.

Hemoglobin enters in chemical combination with oxygen and carbon dioxide in the blood in considerably larger amounts than can be physically absorbed. The oxygen gas content in the blood of an adult is 30 to 60 times higher, and its carbon dioxide content even greater, than the amount that can be present by the laws of physical absorption. When decomposition of the hemoglobin takes place in connection with the maceration process, its specific capacity chemically to combine with oxygen and carbon dioxide is annulled. The amount of gas then liberated is probably considerably greater than the amount that can be physically absorbed in the blood fluid available. In the author's opinion, the resulting difference seems to be the essential factor responsible for the development of the free gas in the fetus.

If this explanation is correct, it would follow that the frequency and the amount of the gas should be directly proportional to the following factors: 1) the degree of maceration, and 2) the amount of hemoglobin. It has already been shown that such a correlation exists with respect to the degree of maceration.

We are now left with the amount of hemoglobin to consider. In an adult, 100 ml blood contains 15 to 16 g hemoglobin. According to most of the information available, the hemoglobin content is larger in a mature fetus than in an adult, varying between 12 and 23 g, corresponding to a mean value of about 17 g. The literature contains only very sparse data on the amounts of hemoglobin in fetuses at different stages of maturation, and the information is in part contradictory. Several authors, *e. g.*

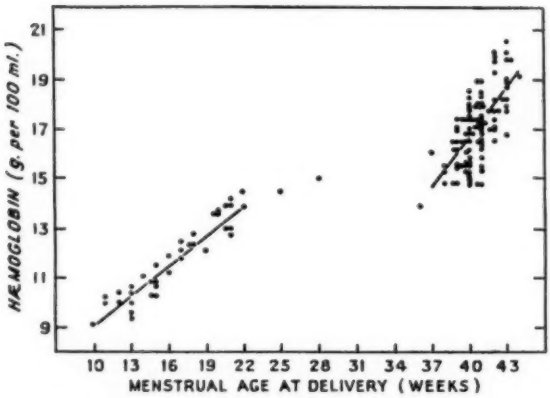

Diagram 3. Haemoglobin levels in cord blood of human fetus in normal pregnancy. (From Walker and Turnbull.)

WALKER and TURNBULL (1953), presume that up to the stage of maturity there is a successive increase in the amount of hemoglobin. This has been disputed by MARKS et coll. (1955), who did not find any correlation between the degree of maturation of the fetus and the hemoglobin content in the blood of the navel.

If the hemoglobin content increases successively with the degree of maturation of the fetus, this, in agreement with the foregoing considerations, would provide an explanation of the fact that the degree of maturation of the fetus is directly proportional to the occurrence of the gas.

The values recorded by WALKER and TURNBULL are reproduced in Diagram 3 and show the amounts of hemoglobin per 100 ml blood at different stages of fetal maturation in normal pregnancies. For cases in which the fetus was subject to conditions of reduced oxygen supply, some time before the delivery, the same authors have indicated that the curve representing the hemoglobin content rises more sharply.

SUMMARY

The material of cases of intra-uterine death comprised 56 fetuses, of which 32 contained free gas. The only factors which were shown to be connected with the gas formation were the degree of maceration and the degree of maturation of the fetus. This is regarded as confirmation of the view earlier advanced by the author that the free gas corresponds to the difference between the amount of chemically combined gas which is liberated on decomposition of the hemoglobin during maceration and the comparatively small amount of gas which can be physically absorbed by the blood serum.

ZUSAMMENFASSUNG

Das vorliegende Material umfasst 56 röntgenuntersuchte Fötusse, von welchen 32 freies Gas enthielten. Die einzigen Faktoren, welche einen nachweisbaren Zusammenhang mit der Gasbildung haben, sind der Grad der Mazeration und der Grad der Maturation des Fötus. Dieser Befund wird als eine Bestätigung der früher vom Verfasser vorgelegten Auffassung angesehen, dass das freie Gas der Differenz zwischen der Menge chemisch gebundenen Gases, welches beim Zerfall des Haemoglobines während der Mazeration frei wird, und der verhältnismässig geringen Gasmenge, welche physikalisch im Blutserum absorbiert werden kann, entspricht.

RÉSUMÉ

Le matériel de l'auteur comprend 56 foetus, dont 32 contenaient du gaz libre. Les seuls facteurs qui ont un rapport certain avec la formation de gaz sont le degré de macération et le degré de maturation du foetus. Ceci est considéré comme une confirmation de l'opinion déjà avancée par l'auteur, que le gaz libre correspond à la différence entre la quantité de gaz chimiquement combiné qui est libéré par la décomposition de l'hémoglobine pendant la macération et la quantité relativement petite de gaz qui peut être physiquement absorbée par le sérum sanguin.

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FROM THE RADIUM CENTER (MEDICAL DIRECTOR: PROF. JENS NIELSEN),
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AN ESTIMATE OF THE GENETIC DOSE FROM RADIOTHERAPY

by

P. R. Purser and *C. F. Qvist*

Among the recent reports on the genetically significant 'man-made' radiation, little attention has been paid to the effects of radiotherapy. One of the earliest reports we know of, by CLARK, gives an estimated gonad dose of 12 mr per year per head of population, but the methods of obtaining this figure are rather questionable. The British report (3) suggests that the contribution from radiotherapy 'is considerably less than the dose from diagnostic radiology, but probably greater than that from any other source'. The corresponding American report (1) gives no separate figures for these two sources, but sets the total for medical roentgen rays at 100 mr per year. We have therefore tried to obtain a rough estimate of the population genetic dose from radiotherapy by means of a sample survey.

Methods

Our survey covered a well defined area in Copenhagen, with a population of 959,000. Information was collected from the city hospitals and private clinics on treatments to men under 50 years of age and women under 40, who were living at the time (1956) in this region. We have

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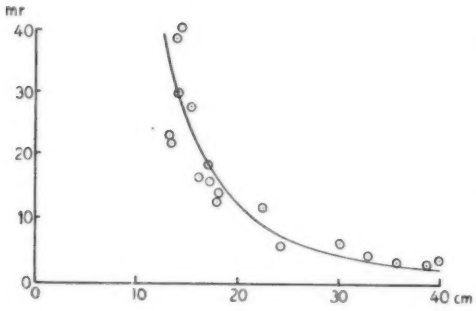

Diagram 1. Gonad dose from radium treatment vs. distance from lesion to gonads. The experimental points are scaled to 1 mC/hr; the curve is calculated for 1 mC/hr assuming soft tissue as the intervening medium.

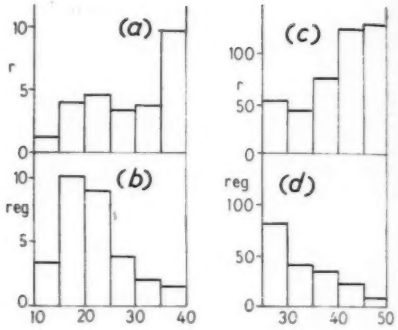

Diagram 2. Gonad dose and genetic dose per million of population analysed into five-year age groups. (a) and (b) are for treatments to arm and hand in women, group 3. (c) and (d) are treatments to hips in men, group 2.

tried to include every therapy treatment with the exceptions of 12 kV skin therapy and all the treatments at two of the skin clinics, where the records were not in a suitable form for our purposes. The age limits were chosen after reference to the official fertility statistics for normal women (5) and a table for men which we constructed by comparison with the figures for England (4). This information was transferred to punched cards for statistical processing. About 700 measurements of gonad dose were taken at four hospitals, one specializing in the more serious malignant cases, and at one skin department. For these measurements we used bakelite-graphite ionisation chambers (obtained from Physikalisch-Technische Werkstätten G. m. b. H., Freiburg, and already described by ZIMMER), placed on scrotum or in rectum.

The estimation of gonad dose from radium treatments was comparatively easy: from a knowledge of the treatment strength in mC/hr, and an estimation of the tumor-gonad distance we could calculate the dose, assuming the intervening medium to be soft tissue; a series of measurements, shown in Diagram 1, indicates that this last assumption is good enough.

For roentgen ray treatments in the normal deep-therapy range (0.8 to 2.0 mm Cu H. V. L.) we found that, for any given region of the body, the dose scattered to the gonads was approximately proportional to the skin dose and the field area.

We therefore divided the body into twelve anatomical regions and analysed our measurements to give a proportionality factor between

gonad dose and the product of skin dose and field area for each region. This relation, of course, only applies when the gonads are outside the direct beam, when stray leakage from the tube and general scatter in the room are negligible, and for patients in a certain size range. We have obtained only one set of proportionality factors for 'good' therapy conditions and for adults. Since deep therapy in children is rare (1 % of the patients in our survey) we neglected this source.

Some of our measurements show that badly shielded (usually antiquated) apparatus can give much higher gonad doses than expected. However, this is most noticeable in those regions giving a very low proportionality factor, and the increase in total population dose from this leakage radiation is probably small. One source of variance in our measurements on treatments to knees in men lay in the various methods of partial protection of the gonads used by some hospitals. We estimate that the factor we obtained might possibly be too low by about x2.

We found no such simple relationship for superficial therapy. However, about one third of these treatments are for hæmangioma in young children. We had already made a series of measurements of gonad dose in a comparison of radium and roentgen ray treatments for this condition, and on the basis of these we were able to estimate the genetic dose from roentgen ray treatments of hæmangioma.

The 12 kV treatments, even to the genital region, were neglected because of the low penetration.

The gonad doses we measured from skin therapy (30 to 60 kV) in adults were so low that we decided that a sample series of measurements was sufficient to estimate the dose from this source without introducing too much error into the total.

In calculating the genetically significant dose, the gonad dose was multiplied by the expected subsequent fertility, *i. e.*, the probable number of children to be produced after the treatment. If the gonad dose is expressed in roentgen, the genetic dose is obtained in roentgen-equivalent-genetic or reg. (4). Since we have statistics for normal people only, the patient material was divided into three groups, on the basis of diagnosis and treatment. The first group, patients expected to have zero or very low fertility, was excluded from the data. The second and third, those with reduced and normal fertility, respectively, were processed separately though as a first approximation; normal fertility tables were also used for the second class, pending a closer idea of the actual fertility in this group. Examples of the diagnoses put into these groups are: 1) *c. uteri*, sterilization treatment for *c. mammæ*, 2) Hodgkins' disease, acromegaly, and 3) tendovaginitis. As a result of this classification nearly all the treatments involving the gonads in the direct beam were excluded from the data as belonging to class one, and most of the treatments to the

abdomen, where our proportionality factors carry the greatest variance, fell into the lower fertility group. One treatment, for a benign condition, which involved one ovary in the direct beam was calculated from depth dose data.

Results and discussion

The results for deep therapy in adults are shown in the Table below; for each anatomical region we have given the proportionality factor expressed as

$$\frac{\text{gonad dose (in roentgen)} \times 10^6}{\text{skin dose (in roentgen)} \times \text{field area (in cm}^2\text{)}}$$

and the total genetic dose in reg. for our population divided into two fertility groups.

Table

Proportionality factors between gonad dose and the product of skin dose and field area for the various body regions, with the corresponding total genetic doses in reg. for low and normal fertility groups (groups 2 and 3 respectively). Population: 959,000.

Region	Men			Women		
	Proportion. factor	Genetic dose group 2	Genetic dose group 3	Proportion. factor	Genetic dose group 2	Genetic dose group 3
Head	1.5	6	2	1.2	5	2
Neck	1.7	8	1	1.3	2	1
Chest	2.2	13	1	3.4	30	10
Shoulder and upper arm	1.0	2	6	1.3	2	13
Lower arm and hand	2.1	0	26	0.9	0	31
Upper abdomen	31	94	0	40	65	1
Lower abdomen	132	191	0	—	0	30
Male genitals	400	4	0	—	—	—
Hips and pelvis	60	177	83	97	202	1
Lumbar spine	20	90	18	49	126	9
Thigh and knee	12	2	47	5.5	0	15
Leg and foot	4.6	1	16	1.2	0	6
Totals		588	200		432	119

To these figures must be added the genetic dose from radium therapy. Here the results for group 2 (lower fertility) are negligible; in group 3 we have 36 reg. for men and 136 reg. for women. Our impression from checking the treatment data is that this dose is almost entirely due to hæmangioma therapy. The number of radium and soft roentgen ray treatments for this condition are roughly equal, and the roentgen ray treatment gives about one tenth of the gonad dose from the equivalent radium therapy. We would therefore estimate 5 reg. for men and 10 reg. for women for this type of treatment.

From our sample series of measurements of gonad dose from skin therapy we estimate the genetic dose to be 20 reg. And from a simple

comparison on the basis of the number of patients we estimate the dose from therapy at voltages intermediate between 60 and 180 kV at about 50 reg. for men and women combined.

It is obvious that in setting our age limits of 50 years for men and 40 years for women we may have missed some of the genetically significant treatments. It might be thought that the decrease in fertility with age would be more than offset by the increase in frequency of treatments. We have therefore analysed some of our data into age groups and the results are shown as histograms in Diagram 2. It seems that our approximation is near enough, and we estimate that our total may be low by not more than 10 %.

In order to make some allowance for the reduced fertility of the patients included in group 2 we have asked several experienced therapists for their views. The general opinion seems to be that we should expect about one quarter to one tenth of the normal fertility in this group. Using this estimate we arrive at a figure of about 1 m. reg. per year per head of population, which is about 1 % of the genetic dose from natural sources. The accuracy of this figure we would set at a factor of 2 either way.

The final questions are how far this figure is representative of the average yearly dose in our sample population, and how representative it is of Denmark as a whole. From the way in which our gonad dose figures follow the expected increase with age we would say that the numbers are sufficiently large to be a good representation of the average of our population. After further consultation with experienced radiotherapists we would suggest that the average for Denmark may perhaps be somewhat higher (about 1.5 m. reg.) by reason of higher doses used in benign therapy in other parts of the country.

In conclusion: Even when taking into account the inaccuracies inherent in our methods above we consider that the contribution of radiotherapy to the genetically significant 'man-made' radiation is small enough to be negligible compared with diagnostic radiology.

Acknowledgements

We would like to thank all the hospital and private clinic staff who have helped us in assembling treatment data and taking measurements, and LANDSFORENINGEN TIL KRÆFTENS BEKÆMPELSE for financial assistance.

SUMMARY

By a survey of treatment data and sample measurements of gonad doses the authors arrive at a figure of 1 m. reg. per year per head of population for the genetic dose due to radiotherapy in Denmark.

ZUSAMMENFASSUNG

Durch einen Überblick über Behandlungsdaten und Kontrollmessungen von Gonadendosen erhielten die Verfasser die Grösse von 1 m. reg. pro Jahr und Kopf der Bevölkerung als die genetische Dosis, welche in Dänemark durch radiotherapeutische Massnahmen bedingt ist.

RÉSUMÉ

Par l'étude des facteurs physiques de traitement et par un échantillonnage de mesures de doses reçues par les gonades, les auteurs arrivent au chiffre de 1 m. reg. par an par tête de population pour la dose génétique due à la radiothérapie au Danemark.

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GONAD DOSES RECEIVED DURING THE MEDICAL APPLICATION OF ROENTGEN RADIATION

by

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Very serious consideration is now being paid to the gonad doses which the world population may receive from different sources of ionizing radiation. In the publication 'The Hazards to Man of Nuclear and Allied Radiations' (1) such sources are listed in Chapter 5. It is seen from the tables that the natural background is responsible for the dominant radiation load, which is therefore indicated as 100 per cent.

Diagnostic radiology is tabled as the next important source of irradiation. It is assessed as 'at least' 22 per cent of the gonad dose coming from the background. This assessment, however, is based upon dose figures from a few hospitals in London only (6) and evidently there is scope for an adjustment of these figures.

Generally speaking, the gonad doses will depend on such factors as the electric data of the roentgen apparatus, speed of films and intensifying screens, the degree to which the roentgen beam is confined, etc. The gonad doses measured are consequently bound to vary with the equipment and the working technique employed.

A second point to consider is how the exposure doses received by a certain group of a population, the patients, should be evened out over the whole in order to give a reliable picture of the radiation received

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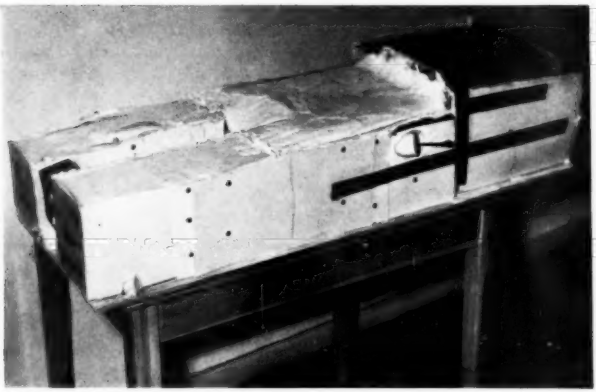

Fig. 1. Dummy used in the investigation.

by the two sexes, and their age groups. Only by means of such an analysis of the statistic distribution can we obtain realistic information concerning the genetic risks.

In the present work the authors have limited themselves to readings of the skin, volume, and gonad doses in diagnostic radiology, measured on four different roentgen stands and three different roentgen plants. The data are augmented by some observations from dental roentgen diagnostics and the roentgen treatment of benign diseases.

Technical data

The technical details of the research set-up were as follows:

1. All roentgen equipment was either of Central European or Swedish manufacture.

2. All the diagnostic roentgen apparatus had four rectifying valves in a Graetz circuit, giving full-wave rectification.

3. The tube filter was about 2 mm Al, including inherent filtration.

4. The two dental roentgen sets compared were of Central European and British make. They were self-rectifying and had the filters as fitted by the makers.

5. The roentgen treatment machine was of Central European origin and showed a near DC high tension curve, secured by its Greinacher circuit.

6. The condenser chambers used for the measurements were of Norwegian make. They were thimble chambers of the following sensitivity

ranges: 0 to 0.1 r, 0 to 20 r and 0 to 100 r, all calibrated against our open-air standard ionization chamber. The 0 to 0.1 r chamber had a reduced capacity in order to keep its volume down to a minimum (5).

7. For charging and reading off doses of the chambers a Norwegian made Moxnes electrometer was used.

8. In order to facilitate the research work the female and male gonad doses were measured on a dummy. The Institute of Anatomy in Oslo supplied the lower part of a spine, a pelvis and two femurs, around which a phantom of Mix D (7) was built up complete from the neck down to the knees. The thorax volumes were filled with foam rubber of a density of about 0.3. The stature was that of a 'standard person of 70 kg'. When exposures of the head and feet were wanted, suitable, pressed wood phantoms were placed in the right positions.

The female gonad doses were measured through an oblique channel drilled to the exact site of the left ovary. When the channel was not wanted it was plugged by means of a wax rod.

In a few cases, *e. g.* in mass chest roentgenography and in dental roentgen work, the male gonad doses were measured directly on living persons.

9. All measurements in the medical roentgen field, both in diagnostics and therapy, were carried out in the Roentgen Department of the University Clinic, Oslo. Care was taken to obtain all readings under normal conditions. The working technique as to patient positioning, etc. was no better and no worse than in the daily routine work.

10. The diagnostic exposures were adapted to meet the speed of medium fast intensifying screens. A dose of 15 to 20 mr is considered as sufficient to give the film a good density.

The data compiled in this way are rendered in the following tables.

Roentgen treatment of benign diseases

Object	FSD cm	Field size cm	kVp	mA	Filter mm	Skin dose r	Gonad doses mr		Remarks
							♀	♂	
Hip	40	10×15	170	15	0.5 Cu	100	3,900	7,300	Lying position
Lumbo-sacral region	»	»	»	»	»	»	37,000	7,500	» »
Knee	»	»	»	»	»	»	20	120	» »
Thoracic vertebrae	»	»	»	»	»	»	80	12	» »
Shoulder	»	»	»	»	»	»	24	14	» »
Hands	»	»	»	»	»	»	85	160	Sitting position, hand resting on table
Feet	»	»	»	»	»	»	19	70	Lying position

Roentgenography on universal stand

n = negligible, < 1 mr

Object	FFD cm	Field size cm	kVp	mAs	Skin dose per exposure r	Number of expos.	Total skin dose r	Total volume dose gram-roentgen	Total gonad dose mr	
									♀	♂
Lungs, p.a.	150	35×35	80	27	0.2	1	0.2	1,800	1.0	n
» , lat.	150	24×30	95	60	0.7	1	0.7	3,700	1.5	n
Bronchogr. p.a.	150	24×30	85	30	0.4	4	1.6	6,200	n	n
» , oblique	150	24×30	90	48	0.6	4	2.4	12,000	n	n
» , lat.	150	24×30	110	72	1.4	2	2.8	15,000	n	n
Heart, p.a.	200	35×35	84	30	0.1	1	0.1	900	n	n
» , oblique	150	24×30	100	60	0.9	4	3.6	18,000	1.7	1.0
Trachea	150	18×24	85	60	0.6	4	2.4	6,100	n	n
Esophagus	100	24×30	85	60	1.2	6	72.2	33,000	n	n
Cervical spine, lat.	150	13×18	80	60	0.5	3	1.5	1,800	n	n
Abdomen	100	30×40	80	180	2.8	3	8.4	59,000	120	7.8
Stomach	60	24×30	75	60	2.2	12	26.4	22,000	144	2.9
Gall-bladder	100	13×18	80	126	2.0	5	10.0	13,500	260	6.7
Urethrogr., a.p.	60	24×30	75	200	8.9	1	8.9	32,500	210	
» , lat.	60	24×30	100	500	34.4	4	137.6	530,000	104	
Myelography, p.a.	60	8×30	75	500	18.4	1	18.4	26,000	252	78
» , lat.	60	12×30	100	500	34.4	2	68.8	177,000	213	31

Horizontal tomography

n = negligible, < 1 mr

Object	FFD cm	Field size cm	kVp	mAs	Skin dose per expos. r	Number of expos.	Total skin dose r	Total volume dose gram-roentgen	Total gonad dose mr	
									♀	♂
Lungs, p.a.	130	24×30	60	200	0.7	10	7.0	23,000	8	2
» , lat.	»	24×30	95	»	1.8	10	18.0	85,000	10	2
Larynx	»	13×18	75	»	1.2	12	14.4	19,000	n	n
Kidneys	»	24×30	68	»	0.9	7	6.3	25,000	165	10
Suprarenal glands, a.p.	»	24×30	80	»	1.2	10	12.0	54,000	360	20
» » , lat.	»	18×24	100	»	2.0	10	20.0	104,000	300	18

Roentgenography on Bucky table

n = negligible, < 1 mr

Object	FFD cm	Field size cm	kVp	mAs	Skin dose per exposure r	Number of expos.	Total skin dose r	Total volume dose gram-roentgen	Total gonad dose mr	
									♀	♂
Abdomen	100	30×40	65	250	3.2	1	3.2	20,000	44	10.8
Pregnancy. Pelvimetry, a.p.	100	30×40	78	310	5.6	1	5.6	39,000	86	
Pregnancy. Pelvimetry, sitting	70	24×30	85	500	19.6	1	19.6	undefined	92	
Pregnancy. Pelvimetry, lat.	90	30×40	85	500	11.8	1	11.8	85,000	76	
Pregnancy. lat. (Placenta)	100	30×40	75	500	7.4	1	7.4	undefined	51	
Cervical spine, a.p. ..	100	13×18	55	250	2.1	1	2.1	2,000	n	n
Thoracic vertebr., a.p.	100	15×40	72	250	3.9	1	3.9	13,000	1.7	2
» » , lat.	100	24×30	75	500	8.4	1	8.4	35,000	5	n
Lumbar vertebr., a.p.	100	24×30	68	310	4.6	1	4.6	18,000	60	4.5
» » , lat.	90	24×30	75	500	9.8	1	9.8	40,000	91	6
Sacrum, a.p.	100	18×24	70	210	2.7	1	2.7	6,000	48	2,200
» , lat.	90	18×24	85	500	11.7	1	11.7	30,000	13	19
Pelvis, a.p.	100	24×30	70	250	3.8	1	3.8	25,000	96	3,580
Hip, Lauenstein pos.	100	18×24	72	250	3.9	2	7.8	18,000	60	7,700
Thigh, a.p.	100	15×40	62	250	2.7	2	5.4	16,000	9.6	73
Knee, a.p.	100	24×30	45	105	0.6	3	1.8	4,000	n	3
Ankle, lat.	100	18×24	45	105	0.6	1	0.6	4,000	n	n

Mass chest radiography

Gonad dose per exposure ♂ 0.11 mr

Dental roentgen diagnostics

Object	FSD cm	Field size cm	kVp	mA	Dose rate r/sec	Skin dose per expos. r [1]
Teeth	17.5	4.5 × 3	70	10	1.5	6.5
»	10.5	4.5 × 3	45	5	2.6	20

[1] Film of ordinary sensitivity.

Fluoroscopy

n = negligible, < 1 mr

Object	FSD cm	Field size cm	kVp	mA	Gonad dose per minute mr	
					♀	♂
Lungs, p.a.	40	30×30	70	3	n	n
Stomach	»	»	»	»	15	0.4
Myelography, p.a.	»	»	»	»	23	5.3
» , lat.	»	»	»	»	17	3.3

Roentgenography on skull table with kVp 56 to 80 and mAs 250 gave a surface dose per exposure of 3.5 to 9.5 r and a total skin dose of 5.3 to 66.0 r. The total volume dosage in gram-roentgen varied between 5,500 and 155,000, but the total gonad dose was in all cases negligible.

No doubt, the skin doses resulting from single and multiple exposures will be of interest. The dose levels vary within wide limits.

It is felt that the volume doses also ought to attract attention. They have been calculated by means of a formula by MAYNEORD (4) and are seen to be of very different orders of magnitude. Even if the relationship between the volume doses and possible harmful effects to the patients has not been established generally, one should at least be able to obtain a certain impression of when and where eventual risks may be encountered.

As to the gonad doses it is evident that they may under certain circumstances be heavy both for female and male patients. Apart from the very best technical means for creating a well-defined field of radiation, other protective measures should clearly be taken. In many cases a covering piece of lead rubber is practicable and therefore recommended. MAGNUSSON (3) has suggested a pair of hinged lead 'shells' to protect the testicles.

More generally, the diagnostic dose levels can be lowered by introducing a heavier radiation filter and even more by using a harder radiation. This again calls for roentgen plants for 125 to 150 kVp or — still better — for three-phase machines (with 6 rectifying valves) (2). Three-phase machines are used extensively in the Scandinavian countries.

It is intended to carry the investigations further and publish the results in a later report.

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SUMMARY

The gonad doses received by male and female patients during the medical application of roentgen rays have been measured systematically on a dummy. Their relationships to the skin and volume doses are shown.

ZUSAMMENFASSUNG

Die Gonadendosen, welche weibliche und männliche Patienten bei der medizinischen Anwendung der Röntgenstrahlen erhalten können, sind systematisch an einem Phantom gemessen worden. Ihre Beziehungen zu den Hautdosen und den Volumendosen werden festgelegt.

RÉSUMÉ

Les auteurs ont systématiquement mesuré sur un mannequin les doses aux gonades que peuvent recevoir des malades hommes et femmes au cours de l'utilisation médicale des rayons roentgen. Ils donnent le rapport de ces doses avec les doses peau et les doses volume.

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ROENTGENOGRAPHY IN HIGH MAGNIFICATION

Reliability and limitation of enlargement

by

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Although the direct method of obtaining a roentgenogram enlarged twice its size is now applied with success in clinical practice, there are some pioneers (3) (5) who doubt whether it is more effective than the indirect method. ADERHOLD (1) and SEIFERT (2) proved by the demonstration of their successful enlargement roentgenography that the direct method of high magnification is far superior clinically to the indirect method.

The purpose of this paper is to discuss from the standpoint of image sharpness and contrast the degree of magnification required in enlargement roentgenography to obtain detailed information on very small tissues not now possible with normal roentgenography.

Since 1953 we have employed a roentgen tube with an autobiased focal spot (4) of under 0.15 mm for enlargement roentgenography (7). We now, however, have at our disposal an improved rotating anode tube with a very fine variable focal spot with a rating of up to 125 kV across the terminals (Fig. 1). The feature of this tube is that the leads from the focusing cap and the heating filament are insulated from each other. The potential of the focusing cap can be varied and made higher than that of the heating filament when a circuit as shown in

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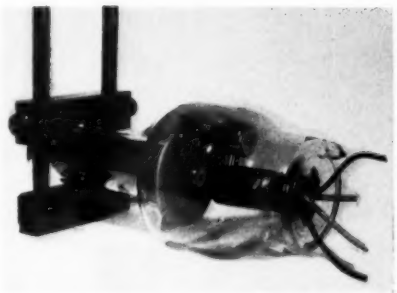


Fig. 1. Rotating anode tube with variable very fine focus.

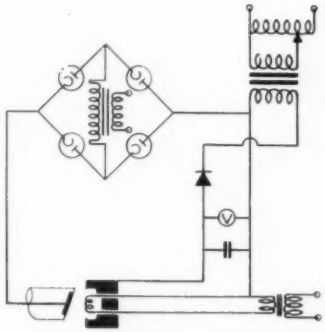


Fig. 2. Circuit showing the connection of high voltage generator (top left), roentgen tube (bottom left) and potential bias regulator (top right).

Fig. 2 is employed. The electronic beam emitted from the filament becomes narrow under the principle of the bias phenomenon and, as a result, the focal spot decreases in size. In roentgenograms enlarged ten times, this tube is capable of resolving tungsten wires of 25 μ in diameter arranged on a test chart parallel to each other with an interval of 25 μ (Fig. 3 b).

It thus becomes evident that if a small lesion has the same opacity to roentgen radiation as tungsten wire, lesions up to 25 μ, which cannot be recognized with the naked eye because of the under-threshold of the resolving power of the eye, may be detected by the procedure. While this type of roentgen tube may be used in roentgenography for actual interpretation, it becomes necessary to determine whether or not the resultant roentgenogram was obtained with such an effective small focal spot because of the variability in the size of the latter. Enlargement roentgenograms of high magnification could be taken by means of a less suitable focus, and the roentgen image considered as diagnostically applicable if some lack of sharpness could be accepted. In a roentgenogram taken with an unsuitable focus, small lesions are not reproduced in the roentgen film, and as a result such a high magnification method could not replace the usual enlargement roentgenography for the examination of minute detail.

In cases in which the size of the focal spot is smaller than the object, the size of the umbrae will remain as the roentgen image even when the ratio of enlargement assumes a larger value than twice the enlargement, and the smaller the focus by comparison with the object, the

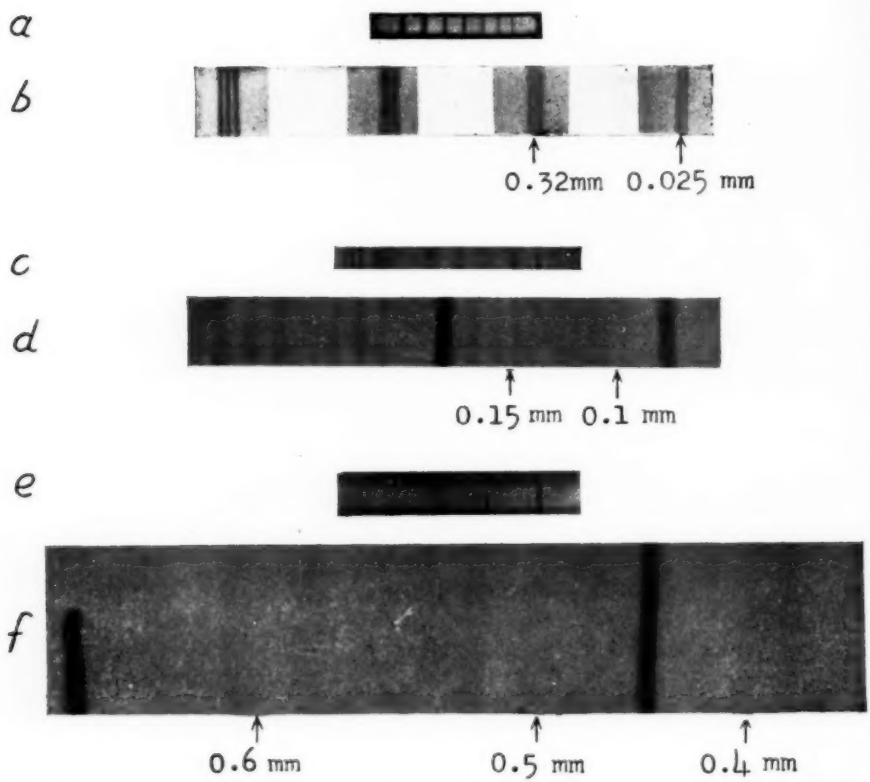


Fig. 3. Ordinary roentgenograms and, respectively, roentgenograms enlarged ten times of: a—b) Test chart of copper; c—d) Test chart of aluminium; e—f) Test chart of acrylite.

sharper the roentgen image becomes. On the other hand, if the size of the focus is equal to or larger than that of the object, only the penumbrae, and not the umbrae, are enlarged when the ratio of the enlargement reaches a high value. The representation of the object then becomes difficult to recognize and fades out (7), *i. e.* small lesions are filtered by the relatively large focus (filter effect).

Fig. 4 shows a roentgenogram of the bone of a toe enlarged five times, obtained with a roentgen tube with a focus of suitable small size, and Fig. 5 a roentgenogram obtained with a tube with focal spots of 0.3 mm. While the first film reveals the fine structure of the bone in situ, the second presents only a very rough structure due to the filter effect (cf. Fig. 6).

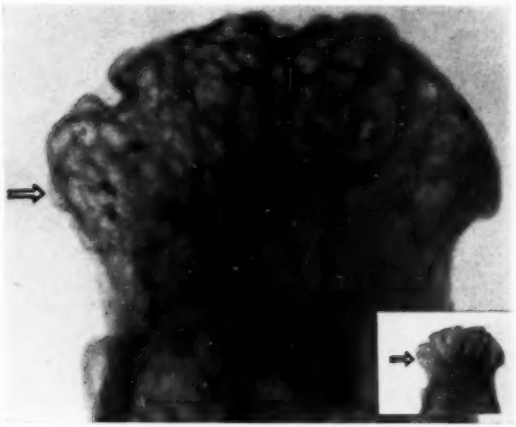


Fig. 4. Roentgenogram of toe, enlarged five times by a suitable small focus tube. Test marker and trabeculation of bone marrow clearly shown (arrow).
Right lower corner: Ordinary roentgenogram of toe with a test marker. Fine structure of trabeculation of bone not seen (arrow).

To avoid misinterpretation of insufficiently enlarged roentgenograms, such as the one shown in Fig. 5, we constructed a small test marker of copper wire which was placed upon the subject and included in the enlargement roentgenogram (8) (Fig. 7). This marker may be inferior to Franke's test chart (3) or to the standard test chart in accuracy but it is very easily constructed and readily available. The reliability of the resolving power of the marker was checked by comparing it with the standard test chart.

The test marker is shown in the roentgenograms in the centers of Figs. 4 and 5. It can be assumed with some degree of accuracy that the roentgenogram in the former was taken with a roentgen tube possessing a resolving power of at least 25 μ, and that in Fig. 5 with a tube with a resolving power of up to only 100 μ. In the latter film no attempt should be made to detect lesions smaller than 100 μ in size.

Although enlargement roentgenography is used within the range of adequate resolution, there is another cause for a lesion remaining unseen during the procedure of image formation. This is the decrease in contrast of the roentgen image in narrow tapered parts of the tissue subjected to high magnification.

We showed experimentally how this taper effect influences the visibility of the object by making three test charts of copper, aluminium, and acrylite (a type of acrylic acid resin, specific gravity 1.2) wires at

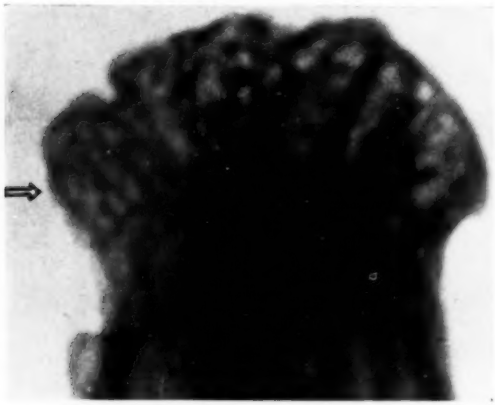


Fig. 5. Roentgenogram of toe. Direct enlargement × 5 by means of an unsuitable tube. The test marker and bone trabecula are not sharp (arrow). The fine structure of the bone is faded out (filter effect).

kilovoltages of 60 and 140, with intensifying screens of a sharpness index of 0.55 tested with a slit width of 0.3 mm after Rudinger-Spiegler's method. Enlargement roentgenograms were made with a background density of 0.1 and studied at the distance of 25 cm from a viewing box with an illumination of 1,700 lux.

Ordinary roentgenograms show that the resolving power is best in the copper test chart, followed by the aluminium, and poorest in the acrylite (Fig. 3). The test chart of copper increases the resolving power as the enlargement increases in ratio, whereas the aluminium chart increases the resolving power up to only four times the enlargement, and then remains stationary. The acrylite chart showed no improvement after the roentgenogram was enlarged to twice its size (Diagram 1).

This is caused by the fact that the 0.1 mm aluminium plate as well as the 0.5 mm acrylite plate at a potential of under 60 kV give a density of just 0.01 which is approximately the threshold of visibility (9). Thus, acrylite, which may be regarded as equivalent to soft tissue in its absorption rate to roentgen radiation, will not be suitable for detecting lesions under 0.4 mm in size. And this is true of bone up to 0.1 mm in thickness. Even roentgenograms enlarged four times or more do not reveal the smaller soft tissue shadows 0.4 mm in size (or 0.4 mm thick to be exact) as, for instance, of the pulmonary markings in the chest (Fig. 9 b). While many linear shadows in the pulmonary fields are increased in enlargement roentgenograms, the size of these shadows does not exceed 0.4 mm, with the exception of those, the contrast of

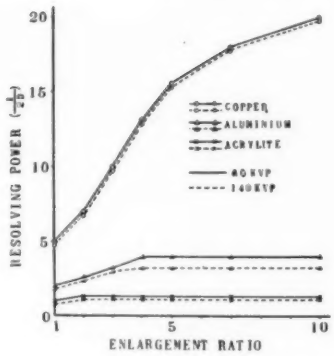


Diagram 1. Relation between the enlargement ratio and the resolving power of test charts made of copper, aluminium, and acrylite.

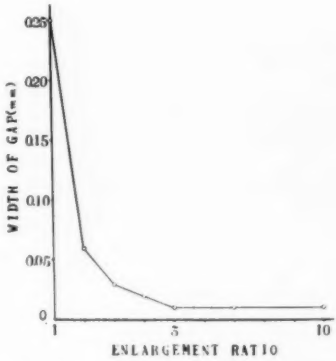


Diagram 2. Relation of visibility of a gap and enlargement ratio.

Fig. 6. Roentgenogram of toe enlarged fifteen times. Trabeculation of bone marrow clearly shown because of the gap effect. No trabecula over 0.1 mm in actual size is reproduced, because of the taper effect. Right lower corner: Ordinary roentgenogram of toe with the magnified part indicated.

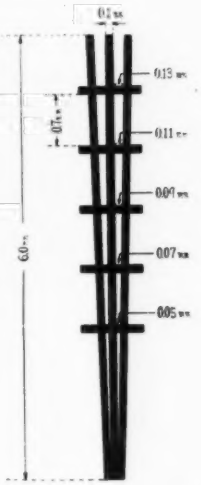


Fig. 7. Schematic illustration of the test marker.

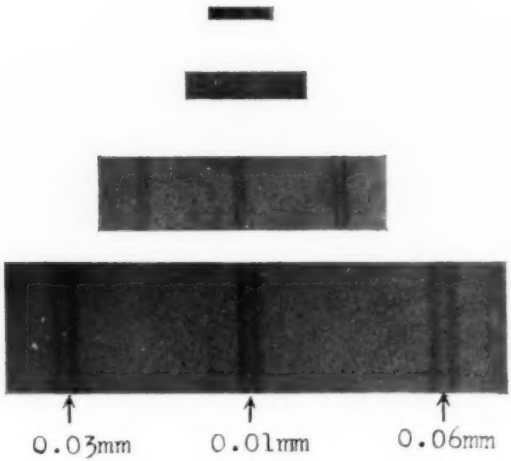
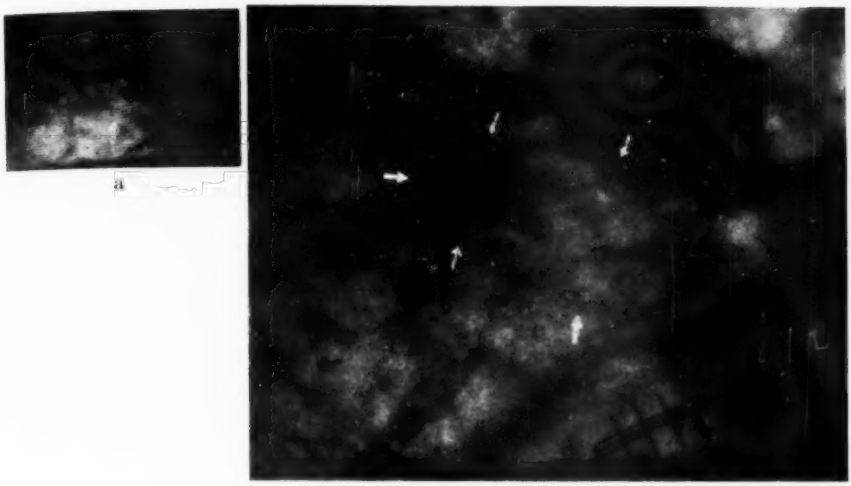


Fig. 8. Roentgenograms of two aluminium wires 0.2 mm in diameter. Increasing magnification. Left: Gap of 60 μ between wires. Center: Gap of 10 μ between wires. Right: Gap of 30 μ between wires.

which would reach over the threshold of the eye only because of superposition of line shadows. These very small shadows do not represent single tissue itself. This poor contrast, caused by the taper effect, may be regarded as the limitation of enlargement roentgenography.

In spite of the limitation of the method for living tissue, for the reason just discussed, our experience has been that the line or fleck shadow in the ordinary roentgenogram is shown in the enlargement roentgenogram, especially when obtained at high magnification. This is the result of the so-called gap effect. When a very narrow gap exists between two objects of fair contrast, this cannot be recognized in an ordinary roentgenogram because of the lack of sharpness caused by intensifying screens and because of physiologic or psychologic factors in the interpretation (6). Such a small gap can be seen clearly when enlargement roentgenography is employed.

In order to demonstrate experimentally how the narrow gap becomes visible between two objects of fair contrast but not of the density of metal, the roentgenographic magnification was increased in steps. Parallel pairs of aluminium wires 0.2 mm in diameter were arranged with variable small gaps between them and roentgenographed by the enlargement technique (Fig. 8). A gap of 250 μ was visible with ordinary roentgenography, that of 60 μ had to be enlarged to twice its size, 30 μ three times, 20 μ four times and, finally 10 μ had to be



a b

Fig. 9. a) Ordinary roentgenogram of normal lung. b) Roentgenogram enlarged four times of part of the lung shown in (a). The lung markings increase the finer shadows through gap effect (arrows). The line shadows, however, do not exceed 1.6 mm in width. Good resolution of test marker. (125 kV, 0.5 mAs, 0.2 sec, 100 cm, Eastman Blue Brand film with high speed intensifying screens.)

enlarged five times before being seen (Diagram 2). The fact that a line or fleck shadow structure is seen with high magnification is thus explained. The fine structure of the trabeculation of bone marrow becomes visible in enlargement roentgenograms, as shown by arrows in Figs. 4 and 6; pulmonary markings are shown in Fig. 9. It is our opinion that this gap effect is one of the most important features of enlargement roentgenography in the demonstration of fine detail. A magnification ratio of at least five will be suitable as far as this effect is concerned.

Acknowledgement

The construction work of the roentgen tube was carried out by Toshiba Electric Co. Ltd. Tokyo.

SUMMARY

Experiments in enlargement roentgenography with a rotating anode bias tube of very fine variable focus capable of resolving tungsten wires of 25 μ in diameter are described. The degree of sharpness was measured by means of a simple test marker. The significance of the influence of the focus size upon the object size ('filter effect'), the difference in the absorption values in different parts of the object ('taper effect'), as well as the enlargement of very small fissures between contrast details in the object ('gap effect'), are discussed.

ZUSAMMENFASSUNG

Bericht über Experimente mit Vergrösserungsaufnahmen mittels einer Drehanodenröhre mit Gittervorspannung und einem sehr feinen, variablen Brennfleck, womit Wolframdrähte von 25 μ Durchmesser abgebildet werden können. Eine einfache Prüfeinrichtung ermöglicht die Beurteilung der Unschärfe. Die Bedeutung des Verhältnisses Fokusgrösse zu Objektgrösse (»filter effect«), der Unterschiede im Absorptionsvermögen in verschiedenen Teilen des Objektes (»taper effect«), sowie der Vergrösserung des sehr kleinen Spaltes zwischen kontrastreichen Teilen des Objektes (»gap effect«) werden diskutiert.

RÉSUMÉ

Les auteurs décrivent leurs expériences de radiographie agrandie avec un tube à anode tournante à tensions de focalisation et à foyer très fin, variable, permettant de radiographier des fils de tungstène de 25 μ de diamètre. Des objets-tests simples permettent d'apprécier le flou. Les auteurs examinent l'importance du rapport des dimensions du foyer à celles de l'objet («filter effect»), de la différence d'absorption des diverses parties de l'objet («taper effect»), ainsi que de l'agrandissement des intervalles très petits séparant des parties richement contrastées de l'objet («gap effect»).

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FURTHER APPROXIMATE STUDIES ON BETA RAY ABSORPTION AND TRANSMISSION

by

Erik Odeblad

The mathematical representation of beta ray absorption and transmission is of great importance and interest from several viewpoints. It may help in the identification of different radionuclides (HAHN and MEITNER 1908) or in the estimation of the maximum beta energy (FEATHER 1938, GLENDENIN 1948), which is of importance in practical applications of activation analysis. The estimation of beta ray dosage in tissues in radioisotope therapy and in radiobiology (MARINELLI, BRICKNERHOFF and HINE 1947, HAHN 1956, LOEVINGER 1956) is founded upon a mathematical representation of beta energy absorption, as is also the calculation of the exposure matrix elements in autoradiography (ODEBLAD 1956). Different practical applications of beta ray transmission measurements also make use of formulae of that kind. [See a review by ZUMWALT 1954, editorial compilation in Nucleonics 1954, and a review by PUBMAN 1955, and original papers by WESTERMARK 1948, ODEBLAD and NORHAGEN 1956.] An excellent review on electron penetration phenomena is that of SPENCER 1955.

The nearly exponential expressions for beta ray absorption and transmission were first discovered by SCHMIDT (1906) and HAHN and MEITNER (1908). Empirical and theoretical data regarding certain radio-

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isotopes were presented by LIBBY (1947). A two-component expression was proposed by LOEVINGER (1950, 1956). CANALS, MARIGNAN and BARDET made some suggestions regarding beta ray transmission (1953). A binominal formula has been suggested by ODEBLAD (1955). In the present paper some theoretical aspects and experimental measurements are presented. One aim is to study if there are measurable differences between transmission curves for different spectral shapes. This problem has been discussed by GLENDENIN (1948). Another scope of the present study is to decide between the exponential and binominal formulae of beta ray transmission.

The notations used are given in pp. 301 and 302.

The exponential and binominal formulae. The customary exponential expression of the transmission $T = (M/M_o)$ of beta rays is the one usually given in common textbooks of nuclear physics:

$$\ln (M_o/M) = \mu r \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1\,a)$$

or

$$-dM/M = \mu\, dr, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1\,b)$$

where r is the 'thickness' of the absorbing foil (usually in g/cm²) and μ is the 'mass absorption coefficient' (usually in cm²/g).

It was originally pointed out by SCHMIDT (1907) that the absorption 'coefficient' (μ) increased with r and that this change in μ was also dependent on the geometry used. As further pointed out by FEATHER (1938) and argued in the author's previous paper (ODEBLAD 1955) the exponential formula predicts an infinite range, something that is not found experimentally.

Starting from the binominal formula for transmission given by ODEBLAD (1955)

$$T = M/M_o = (1 - r/R)^n \quad \ldots\ldots\ldots\ldots\ldots \quad (2\,a)$$

where R is the maximum range (usually in g/cm²) we obtain:

$$dM/M = -n\, dr/(R - r) \quad \ldots\ldots\ldots\ldots\ldots \quad (2\,b)$$

or

$$-n\, dr\, M/R dM = 1 - r/R \quad \ldots\ldots\ldots\ldots\ldots \quad (2\,c)$$

For the initial part of transmission curve where $r \ll R$ we obtain from eq. (1 b) and (2 b):

$$-dM_o/M_o\, dr = (n/R) = \mu \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

which expresses an interrelation between the two modes to describe beta ray transmission. A comparison between the exponential and binominal expressions is presented in Diagrams 1 and 11.

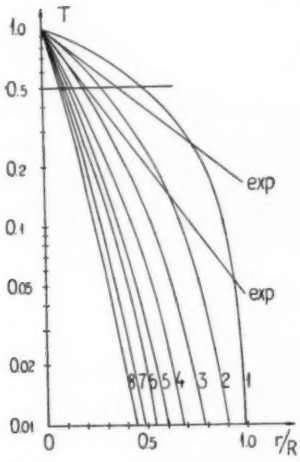

Diagram 1. Binominal and exponential relations in a semi-logarithmic diagram.

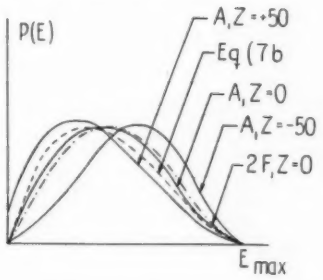

Diagram 2. Approximate theoretical spectral shapes for demonstration of Coulomb and forbiddeness effects on spectral shape E_m = about 0.5 MeV. $A,Z = 0$, allowed, undistorted spectrum, $A,Z = +50$, allowed, Coulomb distorted negatron spectrum, $A,Z = -50$, allowed, Coulomb-distorted positron spectrum, $2F$, $Z = 0$ = second forbidden, $Z = 0$ spectrum. The spectral shape given by eq. (7 b) is also included. For further details see *e. g.* LANGER and PRICE 1949.

Energy loss of beta particles. The BETHE stopping formula for *nonrelativistic* electrons is approximately (See *e. g.* GREEN 1955, EVANS 1955):

$$-dE = (2\pi e^4/E)\, NZ \ln (E/I)\, dx \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where E is kinetic energy, x is the true length of path (cm), $(-e)$ is electronic charge, N is number/cm³ of nuclei of charge $(+Ze)$ and $(I/\sqrt{2})$ mean ionization potential. After introduction of an average energy E_{av} in the logarithmic term we can perform a simplified integration of this stopping formula for the non-relativistic case and find a range-energy relation:

$$\int_0^E 2\, Ed\, E = E^2 = 4\pi e^4\, NZ \ln (E_{av}/I) \cdot X \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

if the slowly varying logarithmic term is regarded as approximately constant. Here X denotes the true length of path. The experimental and theoretical range-energy relation is given *e. g.* by GREEN (1955).

The beta spectrum. A continuous beta spectrum was suggested by the early experiments of SCHMIDT (1907) but was first convincingly shown by CHADWICK (1914). The FERMI theory (1934) has considerably favoured the development in this field.

The spectral distribution $P(E)$ is given by WINTHER and KOFOED-HANSEN (1953), among others, for allowed and superallowed beta transitions:

Table I

Some basic information about classification of beta transitions

Type of decay	Abbreviation	$\Delta\pi$	ΔI	ΔT	Δl	Approx. log. ft	Typical examples	Typical size of matrix element	Some common matrix element notations (Cartesian notation)	Comments
Allowed Super-allowed (favoured).	sa	no	0 or 1	0	0	3.5	H^3	2	$\int 1$ (for $\Delta I = 0$)	Super-allowed transitions usually have very short half-lives
Normal (unfavoured)	a	no	0 or 1	1	0	5	S^{35}	0.1	$\int \sigma$ (for $\Delta I = 0$ or 1, not for $0 \to 0$)	
l-forbidden.....	a, l	no	1		2	6	Zn^{65}	10^{-2}		
1st forbidden										
Unique ...	1st, u	yes	2		3	8	Sr^{90}		Bij	Many common and important radioisotopes belong to these classes
Non-unique ...	1st	yes	0,1 or 2		3	6—8	Sn^{125}	10^{-3}	$\int r \; Bij$	
l-forbidden	1st, l	yes	2		3	8—9	Se^{79}		$\int \gamma 5 \int \sigma r$	
2nd forbidden	2nd	no	2 3			10—13 12	Cl^{36} Na^{22}		$Rij \; Aij \; Tij$	
3rd forbidden.....	3rd	yes	3 4			18 15	Rb^{87} K^{40}			Often long half-lives, low specific activity
4th forbidden.....	4th	no	4 5			23 19	In^{115}			Extremely long half-lives. Very low spec. activity

$$P(E)\,dE = B \cdot F\,(Z,\,E) \cdot p\,(E + mc^2)\,(E_m - E)^2\,dE \quad \ldots\ldots\ldots \quad (6\,a)$$

Here B is given by

$$B = (64\,\pi^4\,m^5\,c^4/h^7) \cdot (g_F{}^2 \left| \int 1 \right|^2 + g_G{}^2 \left| \int \sigma \right|^2) \quad \ldots\ldots\ldots\ldots \quad (6\,b)$$

and $F(Z,E)$ is the Fermi function which expresses the nuclear Coulomb effect. $F(Z,E)$ is given in 'Tables of analysis of beta spectra' and in approximate form by NORDHEIM and YOST (1937) and HOLLANDER, PERLMAN and SEABORG (1953). The factor $F(Z,E)$ has sometimes a profound effect on nuclear beta spectra especially for low energy spectra, and in high Z elements. g_F and g_G are the Fermi and Gamow-Teller coupling constants (See notations). The symbols of the type $\left| \int Q \right|$ represent abbreviations for nuclear matrix elements:

$$\left| \int Q \right| = \sum \int \psi_f\,Q\,\psi_i\,dV \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6\,c)$$

where ψ_f and ψ_i are final and initial wave functions of transforming nucleon and dV any nuclear volume element. The matrix elements express the overlap of final and initial wave functions in the transformation described by the operator Q, which can take on different forms (See *e. g.* the review by ROSE 1955 and KONOPINSKI 1955) for different selection rules in beta decay (Table I).

For *superallowed* beta transitions within one isobaric spin multiplet, one or both of these nuclear matrix elements are around unity or higher (BOLSTERI and FEENBERG 1955, FEENBERG 1955) and slightly less in *normal allowed* transitions (GRAYSON and NORDHEIM 1956). For *forbidden* beta transitions these large matrix elements vanish completely and others of considerably smaller size remain and become dominant. These matrix elements arise from other selection rules and are often energy dependent thus influencing the shape of beta spectrum (See *e. g.* KING and PEASLEE 1954, KONOPINSKI 1955, WU 1955). Some effects of nuclear Coulomb factor and forbiddeness of beta energy spectral shapes are illustrated in Diagram 2. Sometimes the forbiddeness and sometimes the Coulomb effects will dominate the modification of an 'unperturbed' allowed spectral shape, see *e. g.* WU 1955.

For our purpose we shall, in the first step, disregard the Coulomb and forbiddeness effects; these will be mentioned briefly at a later stage. The factor $B \cdot F(Z,E) \cdot p(E + mc^2)$ in eq. (6 a) will within 0.05 to 2 MeV approximately be replaced by bE where b is a constant. This implies, however, compared with the curve $A,Z = +\,50$ of Diagram 2 usually slight underrepresentation of low energy beta particles. We now obtain:

$$P(E) = bE(E_m - E)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7\,a)$$

We obtain from eq. (7 a) approximately by normalization to unit area:

$$P(E) = 12\,E\,(E_m - E)^2/E^4{}_m \quad \ldots\ldots\ldots\ldots\ldots \quad (7\,b)$$

We now define the average beta energy, E_{av}

$$E_{av} = \int_0^{E_m} E\,P\,(E)\,dE \Big/ \int_0^{E_m} P\,(E)\,dE \approx 0.4\,E_m. \quad \ldots\ldots\ldots\ldots \quad (8)$$

For the spectral shape of eq. (7 b) E_{av} is exactly $0.4\,E_m$. (For an easily understandable introductory discussion see SNELL 1951.) A more detailed discussion on E_{av} is given by MARINELLI, BRICKNERHOFF and HINE 1947 and LOEVINGER 1957. Discussions on spectral shape are also found in the papers by HINE 1948 and MARSHALL 1955.

Studies on spectral shape during transmission. The experiments by SCHMIDT 1907 indicated that the average energy of beta rays did not change appreciably after passing

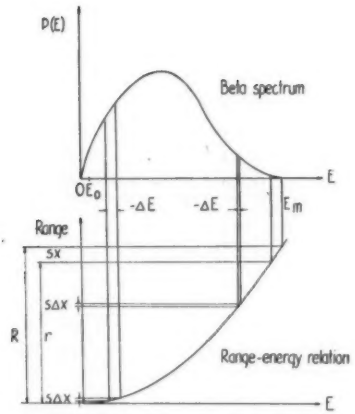

Diagram 3. Non-uniform shift — ΔE towards lower energy in the beta spectrum for a way of path of Δx. The relation between, X, R and r ($sX = R - r$) underlying eq. (11) is here shown.

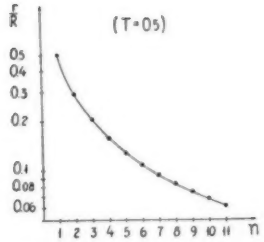

Diagram 4. Values of r/R at $T = 0.5$ for different values of n. The r/R values correspond to the abscissa values at the $T = 0.5$ level in Diagram 1.

through about 0.1 and 0.5 mm of Al. Experiments on monoenergetic electron beams showed, however, that there occur both decrease of mean energy and energy line broadening during transmission (v. Baeyer 1912, Danysz 1913, Bohr 1915, Rawlinson 1915, White and Millingtown 1928, Knop and Paul 1955). Experiments on nuclear beta spectra have indicated that the spectral distribution $P(E)$ does not change appreciably during the beginning of the transmission process (Fournier and Guillot 1933 and Brownell 1952). Obvious changes occurred, however, in these experiments in the beta spectrum as transmission was allowed to proceed further and approached R.

Approximate derivation of binominal transmission formula

The effect in transmission experiments on the beta spectrum can be described as a non-uniform shift of beta spectrum to the left as indicated in Diagram 3. In order to find an expression for dM/M (eq. 2 b), we substitute for M:

$$M = \int_{E_o}^{E_m} P(E)\, dE \ldots\ldots\ldots\ldots\ldots\ldots \quad (9\,a)$$

For dM we find simply, because $P(E_m)$ is by definition equal to zero:

$$dM = d\int_{E_o}^{E_m} P(E)\, dE = -P(E_o)\, dE_o \ldots\ldots\ldots \quad (9\,b)$$

We obtain accordingly by combination of eq. (9 a) and (9 b):

$$-dM/M = P(E_o)\, dE_o / \int_{E_o}^{E_m} P(E)\, dE \quad \ldots\ldots\ldots \quad (9\text{ c})$$

Here dE_o in the numerator is given by the BETHE stopping formula (for non-relativistic beta particles), eq. (4), and $P(E_o)$ is given by eq. (7 b). The denominator is obtained by straightforward integration of eq. (7 b). We now obtain:

$$\frac{dM}{M} = \frac{24\,\pi\, e^4\, NZ \ln(E_o/I)\, dx}{E_m^2 + 2\,E_m E_o - 3\,E_o^2} \quad \ldots\ldots\ldots\ldots \quad (10)$$

In this eq. E_m denotes the maximum energy after zero or finite transmission. If $E_o \ll E_m$ and after substituting energy with range in the denominator according to eq. (5) we find

$$dM/M = K\, dx/X \approx K\, dr/(R - r) \quad \ldots\ldots\ldots\ldots \quad (11)$$

where, by analogy K is identical with n and

$$n = 6 \ln(E_o/I)/\ln(E_{av}/I) \quad \ldots\ldots\ldots\ldots\ldots \quad (12)$$

A relativistic treatment gives a more complicated expression and smaller value for K. Eq. (11) is the binominal formula.

The exponent in the binominal formula. Theoretically n can be calculated in two ways:

1) Eq. (12) implies that n will decrease slowly with increasing E_m.

2) From the expression of μ given by GLEASON, TAYLOR and TABERN 1951 and of R given by GLENDENIN 1948 and GREEN 1955, we obtain approximately

$$n = \mu R = 7.0/E_m^{0.15} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Experimentally n can also be determined in two ways:

1) By interpolation between the family of binominal curves with different values of n (See ODEBLAD 1955). An equivalent method is to interpolate r/R at $T = {}^1/_2$ as is shown in Diagram 4 in which such r/R-values are given.

2) Another method for the determination of n is the comparison of counting rates at an infinitely thin and an infinitely thick sample both containing the same amount of radioactive material.

Considering a layer of thickness dr and having the activity of D disintegrations per mg/cm², the geometry factor being G and the backscattering factor S, we obtain for the counting rate, C an infinitely thick layer

$$C = DSG \int_0^R (1 - r/R)^n\, dr = D\,S\,G\,R/n \quad \ldots\ldots\ldots\ldots\ldots \quad (14)$$

For an infinitely thin layer we obtain simply for the same amount of radioactivity that $C_o = DSGR$.

If the geometry and backscattering factors are equal in both cases, we obtain

$$n = C_o/C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

The relations (12) and (13) and experimental values of n, according to Diagram 4 and eq. (15) are given in Diagram 5.

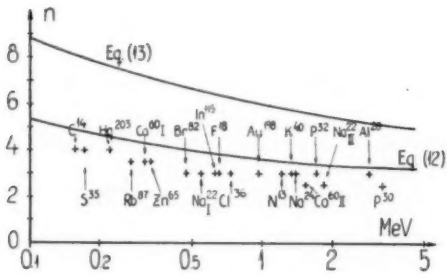

Diagram 5. Relation between binominal exponent, n, and maximum energy E_m, according to eq. (12), eq. (13). The present experimental values of n are also given.

Line spectra. As originally pointed out by BRAGG 1907, the transmission curve of line spectra should not be an exponential function but be similar to the alpha ray transmission curve. Experiments *e. g.* by MARSHALL and WARD 1937 show an S-shaped transmission curve, the end of which approached the exponential shape until the maximum range was reached.

Note on the dimensions of r and μ. It has been pointed out (*e. g.* WESTERMARK 1948) that, other factors being constant, μ varies with the chemical element and compound under study. Such variations in the coefficient μ (See Table II) are considerably reduced if r in eqs. (1 a) to (3) is expressed in electrons per cm² and μ in cm²/electron. This is to be expected as more logical than the g/cm² and cm²/g dimensions because it is mainly the charged atomic electrons and not the nuclear masses that effectuate the stopping of beta particles. The hydrogen and deuterium cases clearly illustrate the situation. Here the mass/cm² changes to the double value due to addition of one nuclear neutron, but the electron number/cm² is practically constant. The cm²/electron for μ has also the advantage of being of the same dimension as a 'cross-section' and can be regarded as the average cross-section for beta ray transmission.

Table II

A. Some absorption coefficients in absolute units

Isotope	μ (g/cm²)	μ electronic, abs. in 10^{-24} cm²/electron
S^{35}	0.21	0.61
Br^{82}	0.052	0.16
P^{32}	0.0078	0.023

B. Some data regarding electron densities

Substance	Electrons/cm² for 1 g/cm²
H_2O	$3.34 \cdot 10^{23}$
Al	$2.90 \cdot 10^{23}$
Pb	$2.38 \cdot 10^{23}$
H_2	$6.02 \cdot 10^{23}$
D_2	$3.01 \cdot 10^{23}$
He	$3.00 \cdot 10^{23}$
air	$3.03 \cdot 10^{23}$

Some information about values of μ and electron densities are given in Table II. μ is here expressed in cm²/g and in cm² per electron (absolute). These quantities are irrelated by

$$\mu\,(\text{cm}^2/\text{electron}) = \mu\,(\text{cm}^2/\text{g}) \cdot s/\Sigma\,(NZ) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

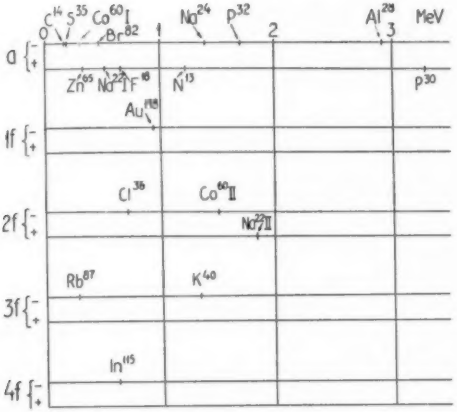

Diagram 6. Beta ray maximum energies of investigated radioisotopes for allowed and forbidden transitions.

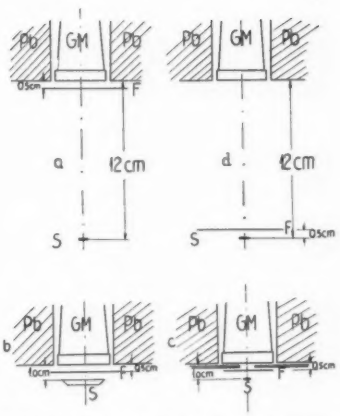

Diagram 7. Geometries of measuring equipments. S = Source. F = absorbing foils.

$\Sigma(NZ)$ can often be calculated from the chemical composition. An experimental method of direct or relative measurement of $\Sigma(NZ)$ has been described by ODEBLAD and NORHAGEN 1956.

Experimental

Eighteen representative well-known radioisotopes with one branch, or two energetically well-separated branches, of beta decay were selected. Beta spectra differing in maximum energy, nuclear Coulomb effect and forbiddeness were studied. (See Diagram 6.) Data were taken from the Table of isotopes by HOLLANDER, PERLMAN and SEABORG 1954, and current New Nuclear Data Cumulation issues of Nuclear Science Abstracts and latest issues of the Physical Review and other physical journals.

The beta ray transmission curves have to be compared under the same 'geometry' of the measuring device. Due to the very great differences in specific activity and beta range for different artificial and naturally occurring isotopes, different geometries were used. Both 'infinitely thin' and 'infinitely thick' samples had to be employed.

In all cases a Tracerlab TGC-2 Geiger-Müller tube was used. The mica window was ~ 2 mg/cm² thick and had a diameter of 2.8 cm. The shielding was 4 cm of lead; the background with empty counter was about 35 c/min. The recovery time was about 110 μ/sec.

In the 'conventional' device the distance between source and tube was 12 cm and the Al absorbers were placed near the tube window, as shown in Diagram 7 (a). When naturally radioactive elements were studied the specimens were placed near the tube (1.0 cm distance) and the absorbers between the source and window, as seen at (b); in some cases of low energy isotopes arrangement of (b) was used with a window of 0.6 cm diameter (c); in some experiments the arrangement of (d) was also employed.

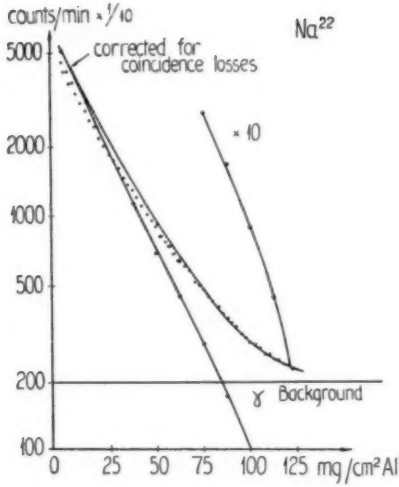

Diagram 8. Transmission data for Na^{22} I beta rays; equipment of diagram 7 (a).

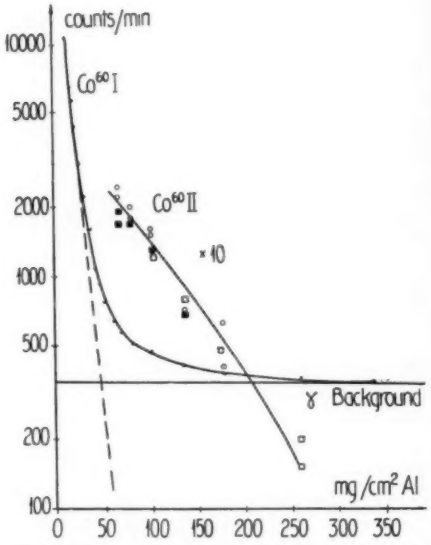

Diagram 9. Some transmission data for Co^{60} I and II beta rays; equipment of diagram 7 (a).

Results of transmission measurements

Results of some transmission measurements are given in Diagrams 8 to 10 and some results of $ndr\ M/RdM$, plotted against r/R in Diagrams 11 and 12. Other results appear in Diagram 5 and Table III. Studies of the experimental results indicate that high degree of forbiddeness or high nuclear Coulomb effect does not profoundly change the transmission curve. In the first approximation, therefore, all the beta emitters considered here would be represented approximately by the binominal formula with the appropriate value of n. The pure exponential representation appears to be less accurate.

The effect of different 'geometries' was studied with the aid of Na^{22}, Na^{24} and P^{32} samples, using very thin and infinitely thick samples as well as different distances from the Geiger-Müller tube and different position of absorbers. Some results are shown in Diagrams 13 and 14. The binominal formula also here appears capable of describing the results with enough accuracy except in the case of Diagram 13, at (*d*).

Table III

Information and experimental data regarding radioisotopes used

Nuclide	Energy, MeV charge	Half-life	Branching	log *ft*	Type	Production reaction	Geometry used	*R* in electrons $\times 10^{23}$/cm²	*n* (exponent)	Comments
C^{14}.....	0.155 —	5,600 y	1.00	9.4	a	n, p	b, c	0.072	4	1
S^{35}.....	0.167 —	87 d	1.00	5.0	a	n, p	b, c	0.087	4	
Hg^{203} ..	0.21 —	47 d	1.00	6.4	1st?	n, γ	b, c	0.16	4	2
Rb^{87}...	0.27 —	$6.2 \cdot 10^{10}$y	1.00	17.6	3rd	nat	c	0.20	3.5	12
$Co^{60}I$ ..	0.31 —	5.2 y	1.00	7.5	a, l	n, γ	b, c	0.25	3.5	3
Zn^{65} ...	0.33 +	245 d	0.02	7.3	a, l	n, γ	b, c	0.29	3.5	4, 5
Br^{82} ...	0.47 —	36 h	1.00	5.3	a	n, γ	b, c	0.49	3	6
$Na^{22}I$ ..	0.54 +	2.6 y	0.90	7.4	a, l?	d, α	a, b, c, d	0.61	3	7, 5
In^{115} ...	0.63 —	6.10^{14} y	1.00	23.0	4th	nat	a	0.6?	3?	13, 12
F^{18}	0.65 +	112 m	1.00	3.6	sa	t, n	a	0.72	3	5
Cl^{36}....	0.71 —	$4.4 \cdot 10^5$ y	1.00	13.5	2nd	n, γ	a	0.78	3	
Au^{198} ..	0.96 —	2.7 d	0.98	7.4	1st	n, γ	a	1.2	3	8
N^{13}	1.21 +	10.1 m	1.00	3.7	sa	α, n	b	1.5	3	5, 12
K^{40}....	1.33 —	$1.3 \cdot 10^9$ y	1.00	18.4	3rd	nat	b	1.5	3	9, 12
Na^{24} ...	1.39 —	15.0 h	1.00	6.1	a	n, γ	a, b, c, d	1.82	3	10
$Co^{60}II$.	1.48 —	5.2 y	0.002	12.6	2nd	n, γ	a	1.8	2.5	3
P^{32}	1.70 —	14.3 d	1.00	7.9	a, l	n, p	a, b, c, d	2.25	3	
$Na^{22}II$.	1.83 +	2.6 y	0.0006	13	2nd	d, α	a	2.3	2.5	7, 5
Al^{28} ...	2.9 —	2.3 m	1.00	4.9	a	α, p	b	3.7	3	11, 12
P^{30}	3.3 +	2.5 m	1.00	5.0	a	α, n	b	4.3	2.5	5, 12

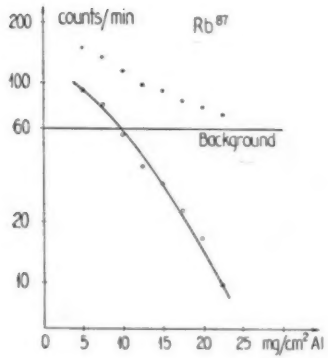

Diagram 10. Transmission data for Rb^{87} beta rays; equipment of diagram 7 (b).

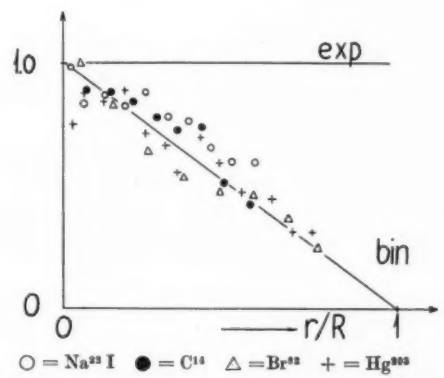

Diagram 11. Plot of $n\ dr\ M/R\ dM$ against r/R for some of the different radionuclides studied. Data normalized by calculating the mean of $n\ dr\ M/dM(R - r)$ and putting this mean = unity.

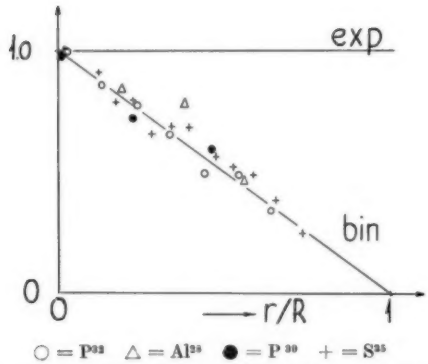

Diagram 12. Plot of $n\,dr\,M/R\,dM$ against r/R for some of the different radionuclides studied. Data normalized by calculating the mean of $n\,dr\,M/dM(R - r)$ and putting this mean = unity.

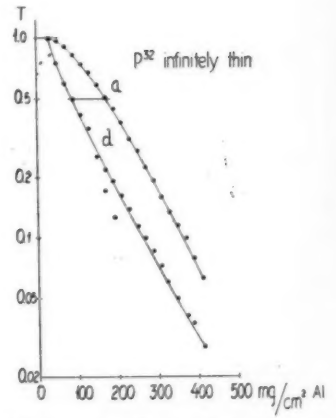

Diagram 13. Transmission curves for an infinitely thin P^{32} source; a) = equipment of diagram 7 (a); d) = equipment of diagram 7 (d).

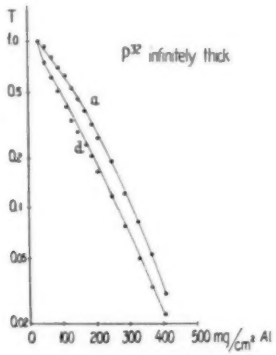

Diagram 14. Transmission curves for an infinitely thick P^{32} source; a = equipment of diagram 7 (a); d = equipment of diagram 7 (d).

Discussion

The theoretical derivations resulting in the binominal formula suffer from several serious simplifications. The most important are the following: 1. Only non-relativistic electrons have been primarily considered. 2. Eq. (5) is simplified through the introduction of the constant value E_{av} in the logarithmic term. 3. The spectral shape used in the derivation is

over- or underrepresented in the low energy region. 4. The experimental studies on the shape of beta spectrum during transmission are insufficient to underlie a precise derivation. 5. No effects of multiple scattering have been included in the calculations.

In spite of these very profound simplifications, the experimental results support the binominal formula as a fairly good approximate description of the beta ray transmission. This may imply that mechanisms are operating which bring about a cancellation of many important factors disregarded in the derivations rather than that such simplifications are justified.

The experimental results indicate that the Coulomb and forbiddeness effects are of relatively small importance in modifying the transmission $T(r)$ from the basic case of an undistorted allowed spectrum. Our measurements have, however, only been performed in the limited energy range 0.17 to 3.3 MeV, so no conclusions should be drawn regarding the usefulness of the binominal formula outside this energy region, *e. g.* for H^3. It was also found that the presence of a weak line spectrum (Hg^{203}) did not affect the application of the binominal formula. For a discussion on high intensity conversion spectra see *e. g.* GLENDENIN (1948) and RUTHERFORD, CHADWICK and ELLIS (1930).

The use of 'infinitely thin' or 'infinitely thick' specimens was found to be of some importance to the transmission curve. The notable exception of the example shown in Diagram 13 (d), from the binominal curve may be due to the very marked effect of scattering effects in this arrangement. Effects of this nature have also been discussed by HINE (1948).

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Grants from the Swedish Medical Research Council, Harald and Greta Jeansson Foundation, Nobel Funds of Karolinska Institutet and Stille-Werner Co., Stockholm, Sweden, have facilitated this work. Mrs Valborg Arnbert is thanked for her assistance in the experimental measurements.

Notations

A	atomic weight	d	operational symbol for differentiation
b	constant eq. (7 a)		
B	factor in eq. (6 a) and (6 b)	D	disintegrations/sec per mg/cm² of sample (eq. 14)
c	velocity of light $3.00 \cdot 10^{10}$ cm/sec		
C	Counting rate in Geiger-Müller tube eq. (14)—(15)	E	kinetic energy of beta particle MeV

E_{av} average kinetic spectral energy eq. (8), MeV
E_o minimum kinetic energy MeV transmitted through GM tube window
E_m maximum kinetic energy of beta spectrum MeV (see also eq. (10))
e electronic charge, $4.8 \cdot 10^{-10}$ electrostatic units
$F(Z,E)$ Fermi function or nuclear Coulomb factor, see "NBS Tables of Analysis of Beta spectra" 1953, or in graphic form HOLLANDER, PERLMAN and SEABORG 1953
g_F Fermi coupling constant in beta decay $\sim 1.4 \cdot 10^{-49}$ erg cm^3
g_G Gamow-Teller coupling constant in beta decay $\sim 1.6 \cdot 10^{-49}$ erg cm^3
G geometry factor in counting with Geiger-Müller tube (G = solid angle)
h Planck's constant $= 6.63 \cdot 10^{-27}$ erg sec
I $I/\sqrt{2}$ = mean excitation potential MeV (see *e. g.* EVANS 1955)
K constant see eq. (11)
ln natural logarithm
M number of beta particles
M_o initial number of beta particles (at $T = 1$)
m electronic mass $9.11 \cdot 10^{-28}$ g
mc^2 electronic rest energy 0.51 MeV
N number of nuclei per cm^3 of charge $+ Ze$
n exponent in binominal formula
μ beta ray absorption coefficient (general), electronic beta ray absorption coefficient eq. (16)
p momentum of beta particle
R maximum beta range (g/cm^2) or (electron number cm^2)
r thickness of layer of penetration (g/cm^2) or (electron number/cm^2)
$P(E)$ approximate beta spectral distribution
Q operator in beta decay
s specific density
S backscattering factor
T transmission of beta rays $T = M/M_o$
V volume cm^3
x length of path cm; $x = r/s$
X length of path, cm; $sX = R - r$ Diagram 1
Z nuclear charge in units of e
$\int$ operational symbol for integration
$\int 1$ Fermi nuclear matrix element in beta decay eq. (6 b)
$\int \sigma$ Gamow-Teller nuclear matrix element in beta decay eq. (6 b)
$\int Q$ general symbol for nuclear beta decay matrix element eq. (5 c)
Σ operational symbol for summation
Δ small shift or change
ψ nuclear nucleon wave function

Special notations for tables I and III

I nuclear spin angular momentum quantum number
T isobaric spin quantum number
l nucleon orbital momentum quantum number
π parity
ft The comparative lifetime ft is defined by the relation

$$ft\,(\Sigma G^2/\int Q/^2) = H \qquad (17)$$

where G is a general coupling constant and $/\int Q/$ a general matrix element.
The ft values are given in seconds

$$H = 2\,(\ln 2)\,h/\pi^4 m^5 c^4.$$

Comments on Table III

1. C^{14} has abnormally high log *ft* value for being a normal allowed transition.
2. Hg^{203} beta decay goes to an excited state of Tl^{203}, which is de-excited by emission of 0.28 MeV gamma rays. The conversion coefficient is 0.15. The energy of conversion electrons is 0.21 MeV and appears just at the high energy end-point of the beta spectrum.
3. Co^{60} The low energy branch (I) goes to the second excited state of Ni^{60} and the high energy branch (II) to the first excited state. The energies of the gamma rays are 1.33 and 1.17 MeV respectively. The conversion coefficient is about 10^{-4} for both gamma transitions so that the conversion electrons (of about 1.1 MeV energy) form about 1/10 of Co^{60}II beta rays.
4. Zn^{65} The gamma rays of 1.12 MeV energy which are about 20 times as frequent as the beta rays have a conversion coefficient of about 10^{-4}. The conversion electrons are therefore negligible here.
5. Annihilation gamma rays of 0.51 MeV occurs (Zn^{65}, Na^{22}, F^{18}, N^{13}, P^{30}).
6. Br^{82} has a complicated decay scheme due to multiple branching from the Kr^{82} level fed by Br^{82} beta decay. Approximate estimation and measurements suggest that the conversion electrons are of no interest here.
7. Na^{22} The positron decay of 0.54 MeV goes to the first excited level of Na^{22} which is also fed by K capture (about 10 per cent of positron disintegrations). The conversion electrons of 1.3 MeV occur in about 1/6 of Na^{22}II beta decay (of 1.83 MeV positron energy).
8. Au^{198} A gamma ray of 0.41 MeV follows the beta ray. The conversion coefficient is about 0.03, so that 0.35 MeV conversion electrons occur in about 3 per cent of 0.96 MeV beta rays.
9. K^{40} decays both with K capture and negative beta rays. A nuclear gamma ray is also present and follows K capture. The gamma rays which are only slightly converted occur about 1/10 as frequent as the negative beta rays.
10. Na^{24} beta decay is followed by two gamma rays of 2.76 and 1.38 MeV, which are very slightly converted. Both another low and another high energy beta component are present to a negligible extent.
11. Al^{28} A nuclear gamma ray of 1.84 MeV follows the beta transition. The conversion coefficient is probably very small.
12. Rb^{87}, N^{13}, In^{115}, K^{40}, Al^{28}, P^{30}: R uncertain.
13. Values of Martell and Libby (1950) used.
    Information about beta energies is obtained mainly from Mayer, Moskowski and Nordheim 1951, Nordheim 1951, Mayer 1955, King 1954, and Feenberg 1955.

SUMMARY

Approximate and simplified theoretical considerations result in the binominal formula proposed earlier for describing transmission of beta rays. Experimental measurements on 18 radionuclides are presented and support the preference for the binominal formula rather than the exponential formula. The dependence of the exponent in the binominal formula on maximum beta energy, nuclear Coulomb effects, forbiddeness and geometry factors during measurements have been studied.

ZUSAMMENFASSUNG

Approximative und vereinfachte theoretische Erwägungen ergeben die binominale Formel, welche früher zur Beschreibung der Transmission von Betastrahlen vorgeschlagen worden ist. Experimentelle Messungen an 18 Radionukleiden werden vorgelegt und stützen die Bevorzugung der binominalen Formel vor der Exponentialformel. Die Abhängigkeit des Exponenten der Binominalformel von der maximalen Betaenergie, den Kern-Coulombeffekten, der Verbotenheit sowie den geometrischen Faktoren bei der Messung sind untersucht worden.

RÉSUMÉ

Des considérations théoriques approchées et simplifiées conduisent à la formule binomale déjà proposée pour représenter la transmission des rayons bêta. L'auteur présente les résultats de mesures expérimentales faites sur 18 corps radioactifs et montre qu'ils justifient la préférence donnée à la formule binomale sur la formule exponentielle. L'auteur a étudié l'influence de l'énergie bêta maximum, des effets Coulomb nucléaires, l'ordre de la transition et des facteurs géométriques pendant les mesures sur l'exposant de la formule binomale.

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AUS DEM RÖNTGENINSTITUT BEI DER CHIRURGISCHEN KLINIK DER UNIVERSITÄT MÜNCHEN (VORSTAND: PROF. DR. A. KOHLER)

ÜBER EXPERIMENTELLE GESCHWULSTENTSTEHUNG IN VORBESTRAHLTEN GEWEBEN

von

Reinhard Schober und *Oleg Erdely*

Der Einfluss, den strahlende Energie auf die vitalen Funktionen von Zellen und Geweben ausübt, ist an zahlreichen Beispielen und Objekten untersucht worden. So hat man heute recht konkrete Vorstellungen, wie und wo die Energiequanten an der lebenden Materie ansetzen. Diese Erkenntnisse sind teils physikalisch-chemisch, teils am biologischen Modell gewonnen worden. Auch die Tumorbildung ist ein biologischer Vorgang und die Fähigkeit hierzu praktisch sämtlichen Geweben zu eigen. Wir haben uns gefragt, ob diese Fähigkeit zur Geschwulstbildung auch dann vorhanden ist, wenn die betreffenden Gewebe unter verschiedenen Bedingungen bestrahlt werden, bevor, bezw. während sie dem Reiz eines cancerogenen Stoffes ausgesetzt sind, oder ob die Produktionskraft des Organismus dadurch in qualitativer oder quantitativer Hinsicht verändert wird.

Untersuchungen über die Wirksamkeit ionisierender Strahlen an Gewebekulturen, die einem Cancerisierungsprozess unterworfen werden, sind deswegen problematisch, weil es bisher nicht mit Sicherheit gelungen ist, in vitro echte Carcinome oder Sarkome zu erzeugen — in dieser Hinsicht positive Berichte haben bisher den Nachprüfungen nicht standgehalten.

Bei der Redaktion am 8. März 1957 eingegangen.

Aus diesen und anderen Gründen erschien es am zweckmässigsten, die Untersuchungen an einem sog. Reiztumor durchzuführen, wie er nach Injektion von Methyl-Cholanthren in die Subcutis von Ratten mit nahezu 100 %iger Sicherheit zu erzeugen ist.

Die Wirksamkeit von Röntgenstrahlen auf die Entstehung experimenteller Tiertumoren ist bereits verschiedentlich studiert worden. Fast ausschliesslich wurde an transplantierten Geschwülsten oder an Stämmen mit Spontantumoren gearbeitet. Ausgangssituation und Fragestellung waren also von vorn herein anders als in der vorliegenden Untersuchung. Der transplantierte Tumor bleibt stets ein Fremdkörper im Wirtsorganismus, dessen Leistung sich auf Ernährung und Erhaltung dieses fremden Gewebes beschränkt, aber nichts zu seiner Charakterisierung beiträgt. Inwieweit die dabei gewonnenen Ergebnisse in diesem Rahmen von Interesse sind, wird an anderer Stelle zu erörtern sein.

KOK und VORLAENDER ging es darum, zu untersuchen, ob die Wirkung von Röntgenstrahlen auf die Tumorentwicklung als lokalisierte Reaktion von Geweben aufzufassen ist oder als Folge einer Umstimmung des gesamten Organismus verstanden werden muss. Sie bestrahlten vor Implantation eines Mäusesarkoms das Tumorbett mit verschiedenen Dosen, ohne eine wesentliche Abweichung gegenüber Kontrolltieren zu finden. Dagegen konnten sie eine deutliche Resistenzsteigerung gegen den überimpften Tumor nach vorausgegangener schwacher Ganzkörperbestrahlung erreichen. Sie schlossen daraus, dass die Strahlenwirksamkeit bei Tumoren höchstens zum Teil örtlich bedingt ist, im wesentlichen aber eine Aktivierung des Organismus bedeutet, die in Form einer Bindegewebs- und Zellularreaktion zum Ausdruck kommen soll und eine gewisse, wenn auch zeitlich begrenzte, Immunität dem Tumor gegenüber zur Folge hat.

Ein ähnliches Anliegen hatten MURPHY u. Mitarbeiter. Auch sie kamen zu dem Ergebnis, dass schwache Ganzkörperbestrahlungen den Tieren eine Resistenz gegenüber Impftumoren verleihen. Andere Untersucher (FURTH, MAYNEORD & CLARKSON, GRUENKRAUT, KREBS, ZWERG) machten gegenteilige Erfahrungen — Totalbestrahlungen vor der Implantation schienen Angehen und Wachstumsleistung der überimpften Geschwulst positiv zu beeinflussen —, wobei die Schwierigkeit nicht zu unterschätzen ist, Ergebnisse zu vergleichen, die unter recht verschiedenen Problemstellungen und Versuchsanordnungen gewonnen wurden. Schon hinsichtlich der Dosierung ergeben sich hierbei Unklarheiten, da ein Teil der Arbeiten noch in die Aera der Erythemdosis fällt.

BADE versuchte die Anschauungen von KOK und VORLAENDER über den biopositiven Einfluss der Röntgenstrahlung auf den Organismus im Sinne einer gesteigerten Bindegewebsaktivität gegen den Tumor zu objektivieren, indem er sich besonders für den Zustand des reticulo-endothelialen Systems interessierte. Seine Beobachtung, dass nach Allgemein-

bestrahlung der Wirtstiere (bis 300 r) die Transplantationsgeschwülste besser angingen und sich schneller entwickelten, wollte er auf eine Schädigung des histiocytären Apparates beziehen. Es gelang ihm aber weder eine Lähmung dieses Zellsystems durch Röntgenstrahlen nachzuweisen, noch konnte er sichere Anzeichen für eine Aktivitätssteigerung des reticulo-endothelialen Systems entdecken, wie sie ausser von KOK und VORLAENDER auch von LOEWEN, HEMPEL u. a. behauptet worden war. Das Histiocytengewebe wäre zwar sicher Ausdruck einer Abwehrleistung gegenüber dem Transplantat, eine Beeinflussung durch Röntgenstrahlen aber weder in diesem, noch in jenem Sinne möglich, entsprechend der Resistenz dieses Zellsystems, wie bereits MURPHY und NAKAHARA erkannt haben. Der Strahleneffekt am Tumor sei ein direkter und beschränke sich auf eine unmittelbare Obstruktion des Tumorgewebes.

KAWAKAMI hat betont, dass bei der Entwicklung von Transplantationsgeschwülsten übergeordnete Regulationen nur insofern eine Rolle spielen, als hohe Ganzkörperbestrahlungen die Wirtstiere so schädigen können, dass sie nicht mehr zur Versorgung eines Transplantates in der Lage sind. Für seine Beobachtung, dass nach hoher örtlicher Vorbestrahlung des Implantationsbettes die Tumoren nur sehr kümmerlich zur Entwicklung gelangen, hat er eine plausible Erklärung bereit: Die Schädigung des Tumorbettes, insbesondere des Kapillarsystems, verhindert das normale Einwachsen des Transplantates. Auch JAMAMATA hat darauf hingewiesen, dass die Intaktheit des Bindegewebssystems Vorbedingung für eine Tumorentwicklung ist.

Es sei nochmals betont, dass alle diese Untersuchungen an Transplantationstumoren ausgeführt wurden, d. h., die Geschwulst war bereits vorhanden, und nicht ihre Entstehung unterlag dem Einfluss einer Röntgenstrahlung, sondern nur das Gewebe, das zu ihrer Aufnahme, oder der Organismus, der zu ihrem Träger bestimmt war.

Eigene Untersuchungen

Als Versuchstiere dienten männliche Ratten, die unter gleichen Bedingungen gehalten wurden. Das Tiermaterial wurde in 4 Gruppen eingeteilt. Die erste Serie (I) erhielt Ganzkörperbestrahlungen von 15 r pro Woche, die bis zur Gesamtdosis von 240 r fortgeführt wurden. Bei einer zweiten Serie (II) wurde zweimal wöchentlich das Sacralfeld mit 200 r bestrahlt bis zu einer Gesamtdosis von 3,000 r. Die dritte Serie (III) wurde fünfmal wöchentlich ebenfalls mit je 200 r in der Sacralregion bestrahlt, bis eine Gesamtdosis von 4,000 r erreicht war. Wir benutzten eine mit 0.75 mm Cu gefilterte Therapiestrahlung von 180 kV und 12 mA. Die Sacralfelder wurden mit 4 cm^2 sehr klein gehalten. Um die Konstanz der Einstellung bei diesen kleinen Feldern zu gewährleisten, mussten die

Abb. 1. Serie II. Methyl-Cholanthren-Sarkom von 63 g 169 Tage nach Injektion.

Tiere flüchtig narkotisiert werden. Eine vierte Gruppe (IV), die nicht bestrahlt wurde, diente als Kontrolle.

Nachdem der grösste Teil der geplanten Strahlendosis verabfolgt worden war, wurden jedem Tier 10 mg Methyl-Cholanthren, aufgelöst in 0.5 cm^3 Olivenöl, in die Gegend der Sacralfeldes oberhalb der Schwanzwurzel s. c. injiziert.

Die Tiere vertrugen die Bestrahlungen gut. Nach ca. 130 Tagen — wir haben dieses Intervall »Latenzzeit« genannt — waren bei der Kontrollserie die ersten Tumoren palpabel. Bei dieser gelangten sie mit einer einzigen Ausnahme zur Entwicklung. Allerdings war in einem Falle der Tumor so klein, dass er erst mikroskopisch nachgewiesen werden konnte. In der zweiten Serie wuchsen die Geschwülste sehr schnell und nahmen groteske Ausmasse an. In nur 40 Tagen erreichte ein Tumor beispielsweise das Gewicht von 63 g (Abb. 1).

Bei einem Tier war keine Geschwulst zur Entwicklung gelangt. In der dritten Serie waren im vorgesehenen Zeitraum nur zwei Tumoren entstanden, die in ihrer Grösse sich von der Kontrollgruppe nicht unterschieden. Nach örtlichen Bestrahlungen unter Bedingungen, wie sie bei Serie IV angewandt wurden, kam es bald zu umschriebenem Haarausfall im Bestrahlungsfeld. Die Haut wurde rissig und spröde und zeigte eine Hyperkeratose. Eine Tumorbildung war hier nicht zu beobachten. Nur bei einem Tier entwickelte sich eine Geschwulst von 37 g. Das Bemerkenswerte hierbei ist nun, dass dieser Tumor ausserhalb des Bestrahlungsfeldes lag. Bei der Injektion des Methyl-Cholanthrens dürfte die Nadel seitlich abgeglitten sein, sodass das Depot in einem unterdosierten Gewebsbezirk abgesetzt wurde.

Nach ca. halbjähriger Versuchsdauer wurden die letzten Tiere getötet, ein Teil der Tumorträger zu früheren Terminen, um in die Entwicklungsphasen der Geschwulst Einblick nehmen zu können. Metastasen waren in keinem Fall zu beobachten, dagegen war die örtliche Destruktionskraft der Geschwülste oft schon makroskopisch sehr deutlich. Bei einem Tier hatte der Tumor den benachbarten Knochen zerstört und war in den Bauchraum eingebrochen.

Tiere, die keinen Tumor entwickelt hatten (Serie IV) zeigten beim Abpräparieren der atrophischen Haut an deren Unterfläche einen weisslichen, etwas prominenten Fleck.

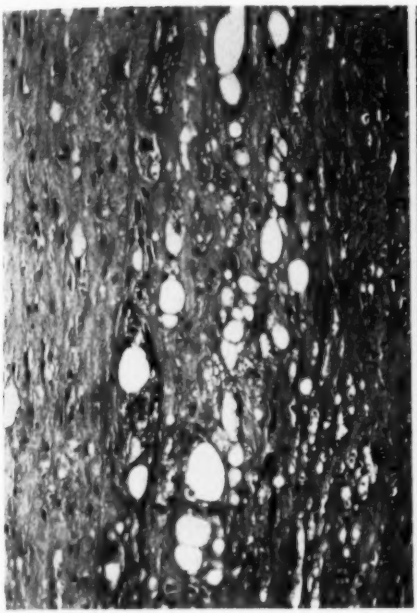

Abb. 2. Serie III. 32 Tage nach Injektion. Öltropfen inmitten eines makrophagen- und riesenzellreichen Granulationsgewebes. v. Gieson.

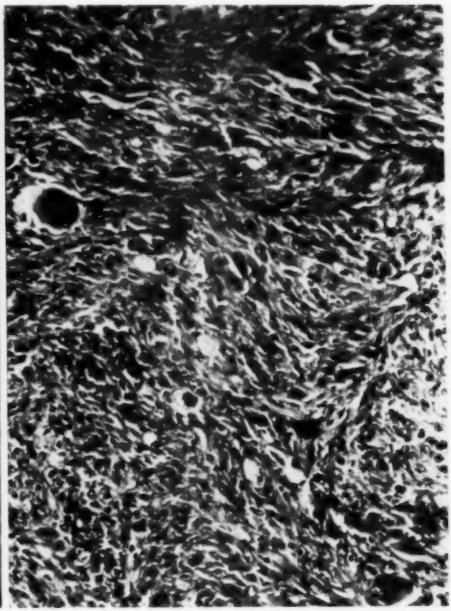

Abb. 3. Serie II. 148 Tage nach Injektion. Fibroplastisches Sarkom mit Riesenzellen. H. E.

Haut des Bestrahlungsfeldes und Tumorgewebe wurden zur histologischen Untersuchung entnommen und nach Formalinfixation in H. E. und nach v. Gieson gefärbt. Ausserdem wurde zur Darstellung fibrillärer Strukturen die Versilberungsmethode nach Pap angewandt. Der Geschwulsttyp liess histologisch in den einzelnen Versuchsserien grundsätzliche Verschiedenheiten nicht erkennen. Es waren durchwegs fibroplastische Sarkome zur Entwicklung gelangt. Je nach Grösse und Ausdehnung der Geschwülste waren mehr oder minder ausgeprägte Nekrosen, Hämorrhagien oder Thrombosen vorhanden.

Die Geschwulst entwickelt sich über das Zwischenstadium eines makrophagenreichen Granulationsgewebes. Das Öldepot wird in zahlreiche kleine Tropfen zerlegt, um die sich wallartig Histiocyten anordnen. Dazwischen finden sich massenhaft granulomatöse Zellinfiltrate. Die Subcutis ist durch ein Ödem verbreitert, aber auch als Folge einer echten Faservermehrung. Dies wird anschaulich in Abb. 2 dargestellt. In späteren Stadien gruppieren sich die Makrophagen wie ein epitheloid-

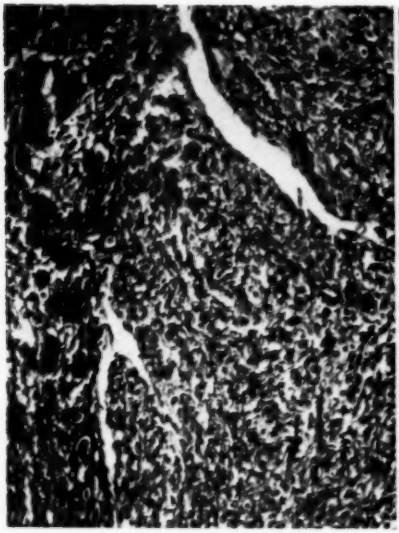

Abb. 4. Serie I. 180 Tage nach Injektion. Faser- und Muskeltrümmer im Tumorgewebe. Versilberung.

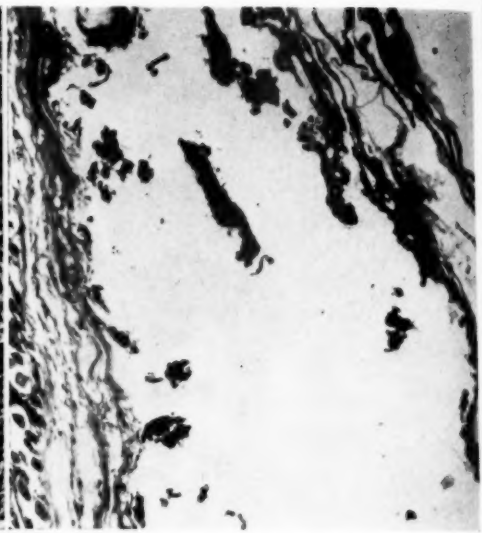

Abb. 5. Serie IV. 151 Tage nach Injektion. Verkalkte Reste des Methyl-Cholanthren-Öldepots in der Subcutis. v. GIESON.

zelliger Saum um die Öltropfen. Das Öl verschwindet schliesslich völlig. Es entsteht ein grosszelliges Gewebe, das mesenchymale Lagerung zeigt, reichlich Zwischensubstanzen in Form teils kollagener, teils noch undifferenzierter Fibrillen aufweist, sowie Riesenzellen enthält, die mitunter dem Tumor ein sehr polymorphes Bild verleihen und wohl als Reminiszenz seiner Entstehungsgeschichte aus einem Granulationsgewebe aufgefasst werden dürfen (Abb. 3). Die Geschwülste lassen sich mit den sog. Resorptionstumoren der menschlichen Pathologie vergleichen.

Trotz des zunächst offenbar rein expansiven Wachstums ist an der echten Malignität dieser Neubildungen nicht zu zweifeln. In den Randabschnitten sieht man den Einbruch in das präexistente Faser- und Muskelgewebe und dessen Zerlegung in grobe Trümmer (Abb. 4).

Die Haut der Tiere in Serie IV (5 × 200 r/Woche) war hochgradig atrophisch, pergamentartig und spröde. Histologisch bestand eine Atrophie des Papillarkörpers, der haarbildende Apparat und z. T. auch die Talgdrüsen waren zu Grunde gegangen. Gelegentlich sah man cystische Erweiterungen der erhaltenen Haarfollikel und Drüsen. Stets vorhanden war eine grob-lamelläre Hyperkeratose, vereinzelt reichten Epithelzapfen von basaliomatösem Aussehen in die Cutis hinab. Hier fanden sich als

Zeichen degenerativer Veränderungen am Faserapparat Hyalinosen, das Gewebe war zell- und gefässarm. In den tiefen Lagen des subcutanen Fettgewebes sah man schollige Verkalkungen, die von einem derben Bindegewebswall umgeben waren. Gelegentlich liess sich hier eine zellige Auskleidung dieser Räume erkennen. Es handelt sich um die Reste des Methyl-Cholanthren-Öldepots, das Kalksalze aufgenommen hatte und praktisch narbig ausgeheilt war (Abb. 5). Bei dem einzigen Tier dieser Gruppe, das einen Tumor entwickelt hatte, der, wie erwähnt, ausserhalb des Bestrahlungsfeldes lag, zeigte die darübergelegene Haut keine auffallenden Veränderungen bis auf eine gewisse Druckatrophie durch die wachsende Geschwulst.

Besprechung der Ergebnisse

Fassen wir das Resultat der Untersuchungen kurz zusammen, so lassen sich folgende Feststellungen treffen:

1. Eine hohe örtliche Strahlenbelastung verhindert in dem betroffenen Gewebsareal die Entstehung eines Methyl-Cholanthren-Sarkoms.

2. Fraktionierte Ganzkörperbestrahlungen mit sehr kleinen Dosen und verteilt über einen grossen Zeitraum, beschleunigen erheblich das Wachstum dieser Tumoren.

3. Fraktionierte Ganzkörperbestrahlungen mit sehr kleinen Dosen und verteilt auf einen grossen Zeitraum bewirken keine schnellere Geschwulstentstehung, verkürzen also nicht die Latenzzeit, sondern fördern nur das Tempo der Geschwulstentwicklung.

Wie kann man sich den Eingriff der strahlenden Energie in diesen Entwicklungsprozess nun erklären? Nach publizierten Untersuchungen lässt sich der Vorgang der Cancerisierung einer Zelle durch Kohlenwasserstoffe so verstehen, dass infolge chemischer Reaktionen von Zellbestandteilen mit dem cancerogenen Stoff ein »Energiehub« ausgelöst wird, der regierende Zentren der Zelle von einem stabilen Zustand in einen anderen überführt. Damit wäre zugleich eine Brücke geschlagen zwischen chemischen krebserzeugenden Stoffen und ionisierenden Strahlen, von denen wir wissen, dass sie ebenfalls chemische Prozesse im Gewebe auszulösen und Energieverschiebungen herbeizuführen vermögen. Es ist weiterhin bekannt, dass auch sie normales Gewebe in krebsiges umwandeln können. Es liegt also nahe, daran zu denken, dass das Methyl-Cholanthren durch die Ionisationsprodukte der Strahlung eine Umwandlung erfährt, oder aber dass der Ablauf der die Cancerisierung einleitenden Reaktionen zwischen Kohlenwasserstoff und Zelle gestört wird. Darüber ist unseres Wissens noch nichts bekannt. Die im Vorliegenden angewandte Versuchsanordnung lässt diese Möglichkeiten nicht ausschliessen, da das Methyl-Cholanthren-Depot bei den örtlichen Bestrahlungen

miterfasst wurde, und da auch die ersten Reaktionen zwischen Kohlenwasserstoff und Gewebe der ionisierenden Strahlung ausgesetzt waren. Bei den Ganzkörperbestrahlungen war das Tumorfeld sogar während der gesamten Entwicklungszeit der Geschwülste — wenn auch in geringem Masse — Ionisationen ausgesetzt. Freilich war der Effekt hier entgegengesetzt.

Eine Klärung, ob Ionisationen den Kohlenwasserstoff, bezw. den zur Geschwulst führenden chemischen Reaktionsprozess zwischen cancerogenem Agens und Gewebe beeinflussen, lässt sich nur erreichen, wenn man nach Abschluss der Bestrahlung und besonders der Strahlenreaktion Methyl-Cholanthren injiziert. Erst dann besteht eine gewisse Wahrscheinlichkeit, dass cancerogener Stoff und Zelle in ihren chemischen Beziehungen zueinander nicht irritiert werden. Nicht nur in der Auslösung chemischer Reaktionsvorgänge im Organismus, sondern auch in biologischer Hinsicht haben Kohlenwasserstoffe und ionisierende Strahlen Gemeinsamkeiten. Beiden Energien ist die Fähigkeit zu eigen, Mutationen auszulösen. In unserem Falle trifft der mutagene Reiz des Kohlenwasserstoffs auf Zellen, die bereits oder gleichzeitig einer ionisierenden ebenfalls mutagenen Strahlung ausgesetzt waren. Wir wissen nicht, was am Gen- oder Chromosomenapparat dieser Zellen hierbei vorgegangen ist, aber wir erfahren, dass die Umwandlung zur krebsigen Zelle sich nicht in gewohnter Weise vollzieht. Hat die Bestrahlung etwa Veränderungen am Erbgefüge der Zelle gesetzt, hat die Zelle eine Mutation durchgemacht, die ihr gänzlich anderes Verhalten gegenüber dem cancerogenen Stoff begründet? Natürlich können solche Überlegungen nur unter der Einschränkung angestellt werden, dass es sich bei der Verkrebsung tatsächlich um einen Mutationsvorgang handelt — eine Ansicht, der immerhin nur von einem Forschungskreis Gültigkeit zugesprochen wird. Die Möglichkeit derartiger Hin- und Rückmutationen durch verschiedene mutagene Stoffe haben TIMOFEEFF u. Mitarb. mit positivem Ergebnis untersucht und das Ereignis »Umklappmechanismus« genannt. Auch RUETISHAUSER denkt an ein solches Geschehen, wenn Rezidive bereits hochbestrahlter Carcinome, die ursprünglich gut auf die Therapie angesprochen hatten, auf weitere Bestrahlungen nicht mehr reagierten und ihre Sensibilität vorloren. Er vermutet darin eine Mutation der überlebenden Zellen in Richtung »Radioresistenz« infolge der vorangegangenen Strahlenaussetzung. Bei Beurteilung der Ergebnisse in Serie IV (hohe örtliche Bestrahlungen) sollte diese Möglichkeit einer gegenläufigen Mutation (»Auslöschphänomen«) nicht ausser Acht gelassen werden.

Sicher sind es aber nicht nur örtlich wirksame Faktoren, die in der bisher aufgezeigten Weise für den veränderten Ablauf der Neubildungsvorgänge verantwortlich zu machen sind. Schon die Tatsache, dass Ganz-

Tabelle

Ergebnisse früherer Untersuchungen über die Beeinflussung experimenteller Tumoren durch Vorbestrahlung des Wirtsgewebes

Wachstumssteigerung: +. Wachstumshemmung: —. Unverändert: Ø.

Ganzkörperbestrahlung			Lokalbestrahlung			
Versuchstier u. Tumor	Resultat	Dosis	Autor	Dosis	Resultat	Versuchstier u. Tumor
Ratten Jensen-Sarkom	Ø	4×10—30 r	Bade			
	+	1×300 r				
Ratten Jensen-Sarkom	+	5—600 r	Clemesen			
Ratten				2×200 r/Wo. 3,000 r	Ø	Ratten Methyl-Cholanthren-Sarkom
Methyl-Chol.-Sarkom	+	16 × 15 r	Erdely	5×200 r/Wo. 4,000 r	—	
Mäuse Spontantumor	+	2 × 400 r	Furth			
Ratten Jensen-Sarkom	+	1 × 540 r	Gruenkraut			
Kaninchen Katos-Sarkom	—	1 × 600 r	Kawakami	2—9,000 r	—	Kaninchen Katos-Sarkom
Mäuse Sarkom	—	1 × 50 r	Kok, Vorlaender	1 × 750 r	Ø	Mäuse Sarkom
Mäuse Transpl. Sarkom	+	3—600 r	Mayneord			
Mäuse Benzanthrazen Sarkom	+	10 × 50 r	Mayneord			
Ratten Jensen-Sarkom	+	100 r	Zwerg			

körperbestrahlungen wohl die Wachstumsleistung der entstandenen Tumoren fördern, also in die Beziehungen zwischen Organismus und Neoplasma eingreifen, nicht aber die Entstehungszeit der Geschwülste verändern — in diesem Sinne wurde der Begriff Latenzzeit gebraucht —, weist darauf hin, dass mit einer Umwandlung des cancerogenen Stoffes und seiner Reaktionsprodukte oder durch ein Ereignis im Chromosomenapparat noch nicht Alles erklärt wird. In Serie II (Ganzkörperbestrahlungen) ist das Prinzip der Verkrebsung mesenchymaler Zellen über ein Granulations- und Resorptionsgewebe erhalten geblieben und nur das Verhältnis der einmal entstandenen Geschwulstanlage zum Wirtstier ist ein anderes geworden.

Andere Untersucher — sie wurden oben bereits zitiert — machten die Erfahrung, dass auch Transplantationstumoren sich anders entwickeln

wenn man das für die Implantation vorgesehene Tier vorher einer Allgemeinbestrahlung unterwirft. Wegen der widerspruchsvollen Ergebnisse haben wir diese in der Tabelle zusammengefasst. Es geht daraus hervor, dass die Geschwülste in den meisten Fällen nach vorausgegangener Ganzkörperbestrahlung eine bessere Entwicklung zeigten. Man hat dies mit einer Resistenzminderung des Organismus durch die Bestrahlung ziemlich umrisshaft zu erklären versucht. Sicher trifft es bei einem Teil in Anbetracht der hohen, meistens im Einzelschlag verabfolgten Dosen zu. MAYNEORD und PARSONS, die einzigen übrigens, die ebenfalls mit Reiztumoren arbeiteten und ein schnelleres Wachstum der erzeugten Geschwülste fanden, haben sich bemüht, die Wirkungsweise etwas näher zu spezifizieren. Sie machten den strahlungsbedingten Lymphocytenzerfall, besonders aber die Schädigung der Erythrocyten, u. a. erkennbar an der Ablagerung freien Eisens im Gewebe, für diese Proliferationssteigerung verantwortlich. Durch den Ausfall von roten Blutkörperchen als Sauerstofftransporter wird ein hypoxämisches Milieu geschaffen, in dem die Geschwülste nun besser gedeihen sollen, wie ORR und STRONG festgestellt haben.

Neben den bisher besprochenen Auswirkungen der strahlenden Energie auf allgemeine Regulationsvorgänge, auf die Zelle, insbesondere ihre regierenden Bestandteile, und eventuell auf die chemische Konstitution des Kohlenwasserstoffe und den Ablauf der energieverlagernden Reaktionen, die sich zwischen diesem und dem Zellapparat abspielen, kommt dem Einfluss der Strahlen auf das örtliche Gefässmesenchym sicherlich eine bedeutsame Rolle zu. Dies gilt besonders für die Erzeugung von Geschwülsten in lokal hochbestrahlten Geweben (Serie IV). Schon die Tatsache, dass man zur Totalschädigung eines Geschwulstparenchyms in vitro eine 10 bis 100-mal höhere Strahlenintensität braucht als in vivo (EBERHARD und CHILDS), weist auf die Bedeutung des bindegewebigen Stromas für die Geschwulstzerstörung hin. SCHOBER hat am Mammacarcinom die Verhältnisse besonders im Hinblick auf die Aktivierung des Bindegewebes nach Vorbestrahlung morphologisch analysiert. LEVIN, MURPHY, ENGEL, APOLANT, ASCHOFF und FISCHERA haben auf die Rolle des reticulo-endothelialen Systems als Träger der Abwehrfunktionen gegenüber dem Tumor hingewiesen. KAWAKAMI sah in der Strahlenschädigung des Gefässapparates die Ursache dafür, dass hier die Tumorimplantate nicht in normaler Weise zur Entwicklung gelangen konnten. In unseren Fällen (Serie IV) waren die Abwehrkräfte des Gefässmesenchyms durch die hohe örtliche Bestrahlung so weit aktiviert worden, dass der Abbau des Methyl-Cholanthren-Öldepots sich beschleunigt vollzog und das Bindegewebe in eine hyaline, gefässarme Narbe umgewandelt wurde. Die Subcutis, vorgesehen als Matrix der künftigen Geschwulst, war atrophisch geworden. Da ferner gefunden wurde, dass

z. B. für die Entwicklung von Benzpyren-Carcinomen ein intaktes Gefässmesenchym notwendig ist, das noch die Fähigkeit zur Entdifferenzierung (»mesenchymale Transformation«) besitzen muss (SCHOBER), erscheint die negative Tumorausbeute in dieser Gruppe sehr verständlich. Das hyaline Narbengewebe der Subcutis, sozusagen in einen biologischen Ruhezustand versetzt, bot die für eine Geschwulstentwicklung notwendigen Voraussetzungen nicht mehr. Hinzu kommt, dass auch die herabgesetzte Durchblutung und Ernährung dieses Gewebes hierfür keine günstigen Vorbedingungen darstellt.

ZUSAMMENFASSUNG

Nach s. c. Injektion einer öligen Suspension von Methyl-Cholanthren entwickeln sich bei Ratten nach ca. 20 Wochen fibroblastische Sarkome. Führt man die Injektion an Tieren durch, die vorher Ganzkörperbestrahlungen oder verschieden hoch dosierte örtliche Bestrahlungen des Injektionsgebietes erhalten haben, lässt sich folgendes feststellen: das Entwicklungstempo der Geschwulst wird erheblich beschleunigt; eine Verkürzung der Latenzzeit (Intervall zwischen Injektion und erstem Sichtbarwerden des Tumors) tritt hierbei nicht ein; nach hoher örtlicher Vorbestrahlung (4,000 r) in diesem Gewebe gelangt kein Tumor zur Entwicklung. Es werden verschiedene Möglichkeiten diskutiert, auf welche Weise strahlende Energie diese Veränderungen bewirken kann.

SUMMARY

A subcutaneous injection of an oily suspension of methyl cholanthrene in rats caused fibroblastic sarcomas to develop after about 20 weeks. When the injections were performed in animals which had previously received whole body radiation or been subjected to more or less large doses of local irradiation at the injection site, it was found that the lesion developed more rapidly; furthermore, no reduction in the latent period (interval between the time of injection and first appearance of the tumour) occurred and no tumour developed after a local pre-irradiation dose of 4,000 r. The possible ways in which the changes might have been effected by the radiation are discussed.

RÉSUMÉ

L'injection sous-cutanée d'une suspension huileuse de méthyl-cholanthrène chez des rats est suivie, au bout de 20 semaines environ, de l'apparition de sarcome fibroblastique. Si on pratique cette injection sur des animaux qui ont subi au préalable une irradiation totale ou une irradiation plus ou moins importante du territoire d'injection, on constate que: le rythme de développement de la tumeur est considérablement accéléré; ceci n'entraîne pas de raccourcissement du temps de latence (intervalle entre l'injection et la première manifestation de la tumeur); après une forte irradiation préalable de ce tissu (4,000 r), il n'apparaît pas de tumeur. Les auteurs discutent différentes possibilités du mode d'action des radiations sur ces lésions.

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BOOK REVIEWS

Die hüftnahen Femurosteotomien unter Berücksichtigung der Form, Funktion und Beansprechung des Hüftgelenks. Von M. E. Müller. 184 S., 282 Abb. Georg Thieme Verlag, Stuttgart 1957. DM. 49.50.

This very interesting monograph deals with osteotomies of the upper end of the femur in various conditions of the hip-joint. The majority of these can, in the author's opinion, be improved or cured by carefully planned osteotomy suited to the individual case. Arthroplasties of the hip ad modum Smith Petersen, Judet and others have not hitherto shown the good late results that were expected of them. A reversion to osteotomy has been widely discussed, and hence this book is highly topical.

The subject matter is presented in a general and a special section. The former is concerned with the strength of and loads on the upper end of the femur with special reference to the general planning of osteotomies. It is based upon Pauwels, investigations and is lucid and concise, in addition to being abundantly illustrated. According to Pauwels, the resultant force upon the femoral head, the *R* line, under normal conditions forms an angle of 16 degrees with the vertical through the head. This angle is smaller in coxa valga and greater in coxa vara (p. 17). In practical application, Müller assumes that the *R* line invariably forms the same angle with the vertical regardless of whether coxa valgus or varus is present. He postulates, too, that it always forms an angle of 22 degrees with the diaphysial axis, which is not the case in coxa valgus and varus. These objections do not, however, affect the discussion in principle.

The general section includes a long chapter dealing with roentgen projections and the examination of roentgenograms with the aid of a specially designed universal measuring instrument, the roentgen ischiometer. The projections described are primarily intended for calculation of the angles required in planning the osteotomy; they are not suited for complete roentgen diagnosis, for among other things there is no lateral projection of the epiphysis and no projections of symmetry of the femoral head and neck.

The special section treats indications, operative methods, and results in subluxations, congenital dislocations, congenital coxa vara, epiphysiolysis, femoral neck pseudoarthroses, coxarthroses, etc. The methods of treatment appear to be well grounded on the whole, but in several instances might be debatable. This applies in particular to subcapital resection osteotomy in epiphysiolysis, which has been performed, however, with or notwithstanding adequate knowledge of the danger of capital necrosis. But the series is too small and the observation time too short for definite evaluation of the hitherto promising results. By and large, this comment also holds good for the other results presented.

For early assessment of the prognosis following subcapital resection osteotomy, the author suggests examination with radioactive phosphorus ad modum Boyd. Simpler and better is the venographic method of Hulth (1956).

The bibliography is extensive and representative, the illustrations are numerous and instructive, and the printing and presentation of the book are outstanding.

Stig Backman.

TOPOGRAPHISCHE AUSDEUTUNG DER BRONCHIEN IM RÖNTGENBILD UNTER BESONDERER BERÜCKSICHTIGUNG DES RAUMFAKTORS. Von Claus Esser. 210 S., 89 Abb. Fortschr. Röntgenstr. Ergänzungsband 66 (2. Aufl.). Georg Thieme Verlag, Stuttgart 1957. DM. 58.—.

This is the second edition of the book which appeared in 1951 and was reviewed in this journal at about that time (Acta radiol. 38 (1952), 80). The arrangement of the book is about the same in the two editions but the text as well as the references have been brought up to date by the inclusion of work done up to and including 1956. One of the more important changes is found in the chapter on the roentgen examination of the bronchi, which has now been enlarged from a previous two pages to cover twenty-four.The author marks ordinary roentgenograms as well as bronchograms and tomograms of the lungs with a series of letters. These indicate, among other things, the side, the direction of the rays, and the posture and position of the patient, so that those who are versed in the code may know at once how the film was taken. It seems to an outsider that to talk about, for example, a RRPHHC film tends to make the going a trifle heavy. Furthermore, this method of marking takes into consideration the direction of the rays in relation only to the thorax. A shrunken or deformed portion of lung often lies in an abnormal position in the chest, and for this reason one must always bear in mind that a roentgen examination should produce a section in vivo, as it were, and not consist of views which are standard as far as the exterior of the body is concerned. Such standard views may of course be employed as aids but must not displace the topographic conception of the examination. The author himself takes great pains to point out the advantages of tomography used in the correct manner, that is to say not only in frontal and lateral projections but with due regard to what it is desired to show.

'The chief value of the book seems to consist in its use as a good reference work for the orientation of the different anatomic variations of the bronchi' were the words chosen to summarize the previous review and may well be repeated as being equally true of the second edition.

Bengt S. Holmgren.

PHYSICS OF NON-DESTRUCTIVE TESTING. Published by the Institute of Physics, London. 72 p, 77 illustrations, 4 tables. British Journal of Applied Physics. Suppl. 6 (1957). 25 sh.

Radiological physicists, and medical physicists in general, will in this book mainly be interested in a paper by prof. C. B. Allsopp on physical methods in medical diagnosis, giving examples of ballistocardiography, thermometry, myography, strain measurements, and xeroradiography. While the other papers are mainly of purely physical and technical content, several optical, acoustic and other examination methods mentioned may well find medical applications also and therefore be of interest to the medical physicists.

Sven Benner.